

NEW ELECTRON TRANSFER MECHANISMS OF SOME ORGANIC REACTIONS

by

SADHANA CHAUHAN



DEPARTMENT OF CHEMISTRY

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

DECEMBER, 1985

TW
CHM/1985/D
CHM C394m
1985
D
CHA
NEW

NEW ELECTRON TRANSFER MECHANISMS OF SOME ORGANIC REACTIONS

A Thesis Submitted
in Partial Fulfilment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

by

SADHANA CHAUHAN

to the

DEPARTMENT OF CHEMISTRY
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
DECEMBER, 1985

21 DEC 1957

CENTRAL LIBRARY

L. I. L., Ltd.

Acc. No. **A** 99207

..... to my parents

who are my source of

strength and inspiration.

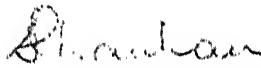
You are
never given a wish
without also being given the
power to make it true.

You may
have to work for it,
however.

STATEMENT

I hereby declare that the matter embodied in this thesis, "NEW ELECTRON TRANSFER MECHANISMS OF SOME ORGANIC REACTIONS" is the result of investigations carried out by me in the Department of Chemistry, Indian Institute of Technology, Kanpur, India, under the supervision of Professor P.R. Singh.

In keeping with the general practice of reporting scientific observations, due acknowledgement has been made wherever the work described is based on the findings of other investigators.


SADHANA CHAUHAN

Kanpur

December 1985

2/1/86

ii

CERTIFICATE

Certified that the work "NEW ELECTRON TRANSFER MECHANISMS OF SOME ORGANIC REACTIONS" has been carried out by Ms Sadhana Chauhan under my supervision and the same has not been submitted elsewhere for a degree.

P.R. Singh 31/12/85

(P.R. SINGH)

Professor of Chemistry
Thesis Supervisor

Kanpur:
December 1985

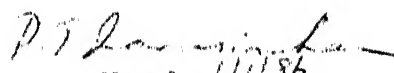
DEPARTMENT OF CHEMISTRY
INDIAN INSTITUTE OF TECHNOLOGY KANPUR, INDIA

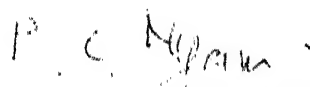
CERTIFICATE OF COURSE WORK

This is to certify that Ms Sadhana Chauhan has satisfactorily completed all the course requirements for the Ph.D. degree programme in Chemistry. The courses include:

Chm 500 Mathematics for Chemists I
Chm 501 Advanced Organic Chemistry I
Chm 502 Advanced Organic Chemistry II
Chm 541 Advanced Inorganic Chemistry I
Chm 800 General Seminar
Chm 801 Student Seminar
Chm 900 Research

Ms Sadhana Chauhan has successfully completed her Ph.D. qualifying examination in April 1982.


Head 1/1/86
Department of Chemistry
I.I.T., Kanpur


Convener 1.1.86
Departmental Post-graduate Committee
Department of Chemistry
I.I.T., Kanpur

ACKNOWLEDGEMENTS

Words have never been able to express sincere thoughts neither will be in future. I therefore wish to express my sincere silent words of acknowledgement to my thesis supervisor Prof. P.R. Singh for suggesting me the research problem and guiding me throughout my mission at I.I.T. Kanpur.

His philanthropy, humanistic attitude, compassion and true affection is beyond expression in words.

The pleasant co-operation of my colleagues Dr. J.M. Khurana, Dr. R.K. Khanna, Dr. N. Govindraaj, Mr. D.S. Udai Kumar and T.V.S. Rao is greatly appreciated. It is a pleasure to thank Mr. S.N. Mishra for his encouragement and help in the laboratory and elsewhere, at all hours. A special word of thanks is due to Mr. K. Rajagopalan for running the IR spectra as and when required and his goodwill.

A special word of appreciation is due to Mr. Anil Johri for his elegant typing of the thesis and Mr. B.N. Shukla for cyclostyling.

My thanks are due to the authorities of the Indian Institute of Technology, Kanpur for financial support.

SADHANA CHAUDHAN

PREFACE

In recent years, the chemistry of organic electron transfer reactions and radical anion intermediates in various organic and organometallic transformations has gained immense significance. Many reactions which formally appeared in the earlier literature to proceed by ionic or unknown pathways have been conclusively proved to involve electron transfer free radical mechanisms. Reports during the past few years, particularly by Professors J.F. Bunnett, C.A. Russell, N. Kornblum, E.C. Ashby, R.K. Norris, G.D. Sargent, S. Bank, J.F. Garst, O.K. Kochi, R.A. Rossi, W.A. Pryor have added newer dimensions to this fast developing field of electron transfer reactions. Radical anion intermediates produced as a consequence of electron transfer, coupling between radicals and anions or atom abstraction from an anion are now found to intervene in a large variety of organic and organometallic reactions. A new mechanistic class of reactions symbolized by $S_{RN}1$ has emerged.

This thesis entitled "New Electron Transfer Mechanisms of Some Organic Reactions" presents mechanistic findings and describes several important aspects of electron transfer mechanisms for reactions broadly classified as (i) the reductive cleavage of diorganomercurials via single electron transfer, (ii) oxidation of α -hydroxy acids and their salts with N-bromosuccinimide, (iii) reduction of primary benzylic halides with sodium naphthalene

(iv) reaction of aromatic aldehydes in the presence of an excess of sodium hydroxide.

The subject matter of this thesis has been divided into six chapters. The first chapter deals with a general review on "Electron Transfer Reactions and Radical Anion Intermediates", based on the existing literature. Each of the chapters II through V has been further subdivided into (1) Abstract, (2) Introduction, (3) Results and Discussion, (4) Experimental, and (5) References. Introduction to each chapter covers a brief literature survey pertinent to the topic under consideration. Sequential numbering of schemes, equations, tables, structures, and references has been repeated for every chapter.

Chapter II presents mechanistic studies on the reductive cleavage of diorganomercurials via single electron transfer. Occurrence of an electron transfer free radical mechanism involving a $\pi^* \longrightarrow \pi^*$ electron transfer from the naphthalene radical anion to the diorganomercurials has been proposed.

Reactions of α -hydroxy carboxylic acids (glycolic, mandelic and benzilic acids) and their salts with N-bromosuccinimide form the subject matter of Chapter III. In view of the relevant observations recorded, it has been proposed that N-bromosuccinimide accepts an electron from the substrate α -hydroxy acid or its anion in the first step of fundamental importance. Succinimidyl anion, bromine atom and the radical derivable by the initial loss

of an electron from the anion of the α -hydroxy acid serve as the precursors of different products.

In Chapter IV, the reactions of four primary benzylic halides with sodium naphthalene have been examined in detail. The major mechanistic pathway in these reactions has been found to be the generation of free radical and the corresponding carbanion intermediates. Existence of a carbene intermediate has also been proposed.

In Chapter V, the available data on Cannizzazo reaction have been discussed and arguments presented to show that the commonly accepted, hydride transfer mechanism is irrational. An electron transfer has now been proposed which appears to account for all the experimental observations.

A summary of the main results and conclusions finally arrived at constitutes the subject matter of Chapter VI.

A part of the work described here has been summarised in the following paper discussed at a National Conference with international participation.

"Reductive cleavage of organomercurials via single electron transfer." P.R. Singh and Sadhana Chauhan at the Second Annual Conference of Indian Council of Chemists held at Srinagar in November 1982.

It is suggested that the importance as well as occurrence of electron transfer reactions involving radical anion intermediates in organic chemistry and also in biochemistry may be much more than previously ever thought.

Particular ²care has been taken to give due credit to the work reported by other authors in the literature. The author is responsible for purely unintentional oversights and errors which could be traced herein.

CONTENTS

	page
STATEMENT	i
CERTIFICATE	ii
CERTIFICATE OF COURSE WORK	iii
ACKNOWLEDGEMENTS	iv
PREFACE	v
CHAPTER I - Electron Transfer Processes and Radical-Anions In Organic Reactions	1
CHAPTER II - Reductive Cleavage of Diorgano- mercurials <u>via</u> single Electron Transfer	63
CHAPTER III - N-Bromosuccinimide Oxidation of α -Hydroxy Carboxylic Acids and their Salts	112
CHAPTER IV - Reduction of Primary Benzylic Halides with Sodium Naphthalene	180
CHAPTER V - A New Mechanism of Cannizzaro Reaction	224
CHAPTER VI - Summary and Conclusion	254

CHAPTER I

ELECTRON TRANSFER PROCESSES AND RADICAL-ANIONS IN ORGANIC REACTIONS

I.1 INTRODUCTION

Occurrence of electron transfer (ET) processes and existence of radical-anion intermediates in organic reactions have been known for over a century. Earliest reports on the existence of radical-anions made by Berthelot¹ and Bechman and Paul², respectively, went unacclaimed for over half a century. Due attention was not given to Kenner's^{3a} statement that "radicals rather than ions are produced more frequently in organic reactions than is usually realized" and his suggestion^{3b} made as early as in 1945 that organic reactivity should be recognized in terms of oxidation and reduction processes until about fifteen years back when Professors G.A. Russell, N. Kornblum and J.F. Bunnet provided experimental evidence in favour of electron transfer processes involving radical-anion intermediates in several reactions formally

classified as nucleophilic displacements. Significant contributions have been made since then, through the pioneering researches of Professors M. Szwarc, G.D. Sargent, J.K. Kochi, W.A. Pryor, S. Sank, H.O. House, J.A. Wolfe, J.A. Marshall, R.A. Rossi and several other eminent scientists to this fast developing area of immense chemical and biochemical importance.

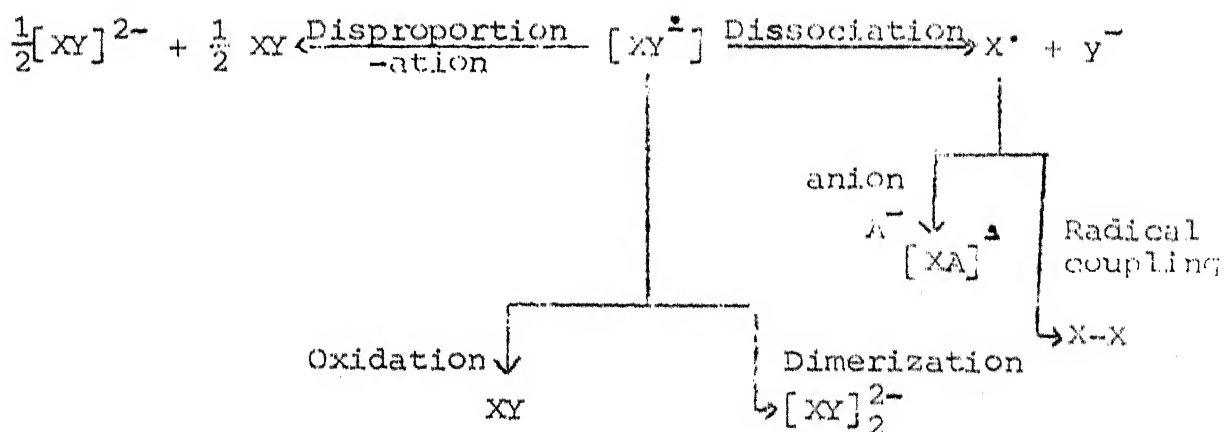
I.2 RADICAL-ANIONS: FORMATION AND REACTIONS

A radical-anion may be formed by a single electron reduction of an appropriate molecule either chemically, photolytically or electrolytically (Eqn. 1)



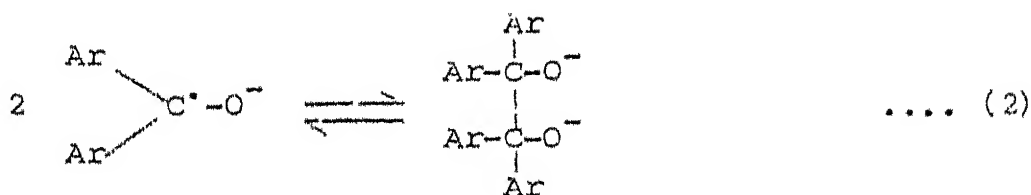
This odd electron species with an overall negative charge, may undergo various types of reactions outlined in Scheme I.1.

SCHEME I.1



A wide variety of chemical species are known to act as donors in electron transfer reactions. For example, metals⁴⁻¹³, organometallic reagents and carbanions¹⁴⁻²⁵, anions²⁶⁻³², metals in their lower oxidation states³²⁻⁴⁰, Lewis bases⁴¹⁻⁴⁷ and alkyl radicals^{40,48-51}, are known to donate electrons to appropriate substrates. Carbonium ions⁵²⁻⁵⁴, metal ions in their higher oxidation states,^{35,55-57} aromatic hydrocarbons,^{55,58-64} molecules with electronegative substituents,⁶⁵⁻⁶⁷ and radicals^{7,68-69}, accept electrons to produce corresponding radicals, metal ions in lower oxidation states, radical-anions or anions, when energy requirements are satisfactorily met.

Formation of radical-anions and their reactions have been extensively reviewed.⁷⁰⁻⁸² ESR,⁸³⁻⁸⁶ UV⁸⁷⁻⁸⁸ and CIDNP⁸⁹ studies have, in recent years, gained popularity as important tools for investigation of radical-anions. Early observations of Bechman and Paul² formed the basis of extensive studies on metal ketyls. The intense blue coloration in the reaction of sodium metal with benzophenone under nitrogen atmosphere was believed to arise from the formation of a metal ketyl which possessed⁹⁰⁻⁹⁷ free radical nature. That ketyl radicals are in equilibrium with diamagnetic pinacولات (Eqn.2) was concluded by magnetic susceptibility measurements.^{94,95,97}

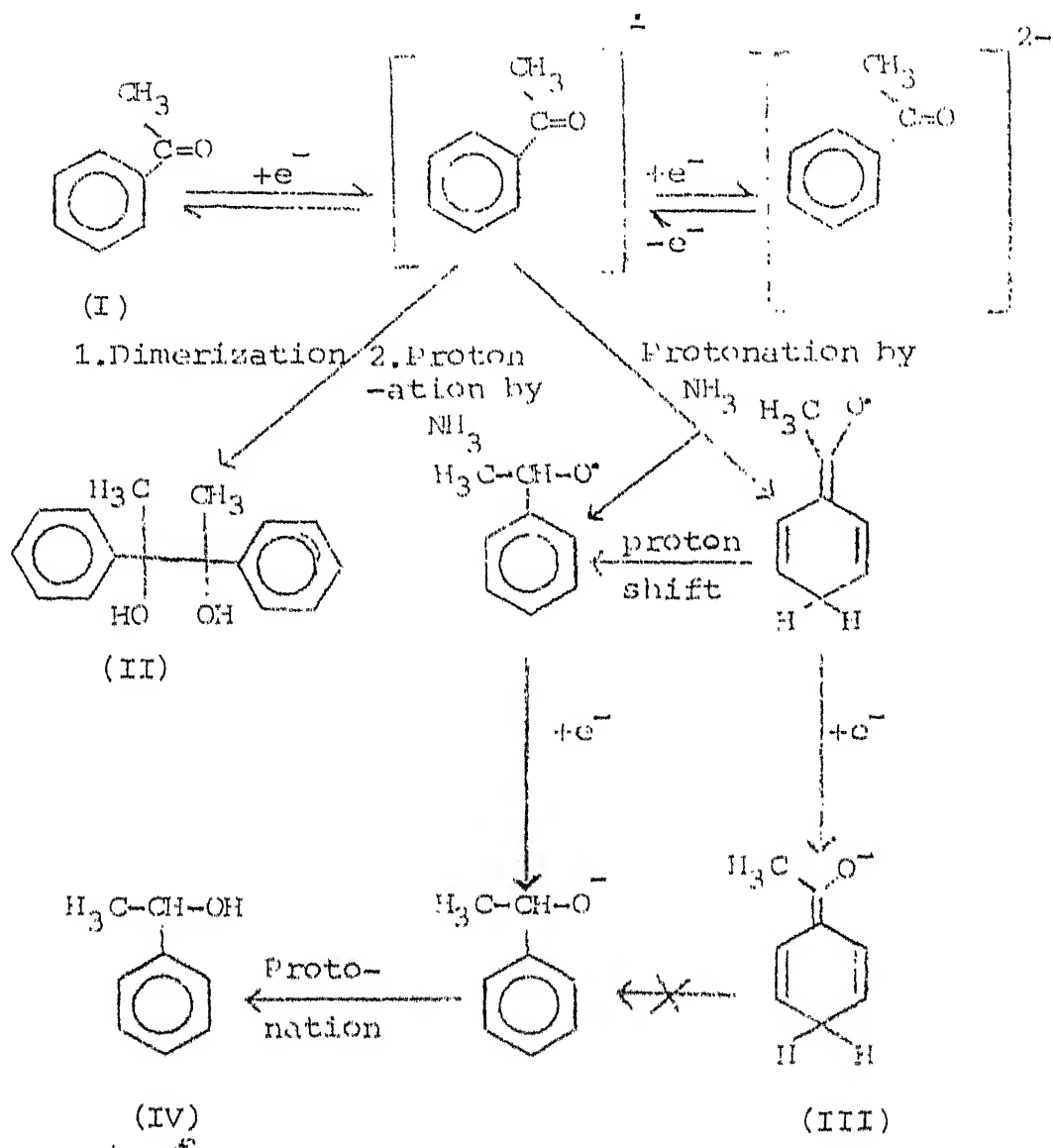


Solutions of alkali/metals, as well as calcium, magnesium, zinc and iron in liquid ammonia,¹⁰⁵⁻¹⁰⁶ low molecular weight amines,¹⁰⁷⁻¹⁰⁹ or ethers like dimethoxyethane (DME) and tetrahydrofuran (THF)¹¹⁰ are known to reduce a variety of organic substrates.⁹⁸⁻¹⁰⁴ Such reactions are now understood as internal electrolytic reductions¹¹¹ in which an electron is transferred from the metal surface or the metal in solution to the organic molecule under consideration.

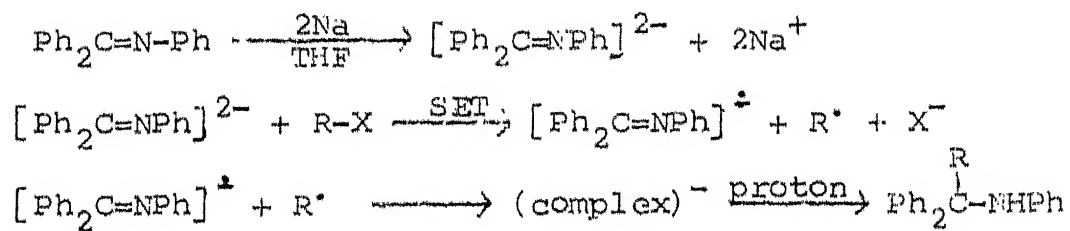
Reduction of several organic compounds of the type >C=N , where X= N-, O, C< or S has been accomplished by the use of alkali metal/solvent reagents. Radical-anions and monomeric as well as dimeric dianions are formed in these reductions, which undergo further transformations to yield final products. For example, the reduction of acetophenone (I),¹¹² with lithium in liquid-ammonia gives 2,3-diphenyl butane-2,3-diol (II), 1-(cyclo-hexa-2,5-dienyldene) enolate (III) and 1-phenyl ethanol (IV) as shown in Scheme I.2 on next page.

The monomeric dianions formed in the reduction of -C=N- bonds¹¹³⁻¹¹⁵ by single electron transfer (SET) from alkali metals in protic solvents, not only act as nucleophilic reagents^{113a}, but also participate in electron transfer processes.^{113b} This is illustrated by the reaction of benzophenone and alkyl halides in the presence of Na/THF which is believed to proceed as shown in Scheme I.3.

SCHEME I.2



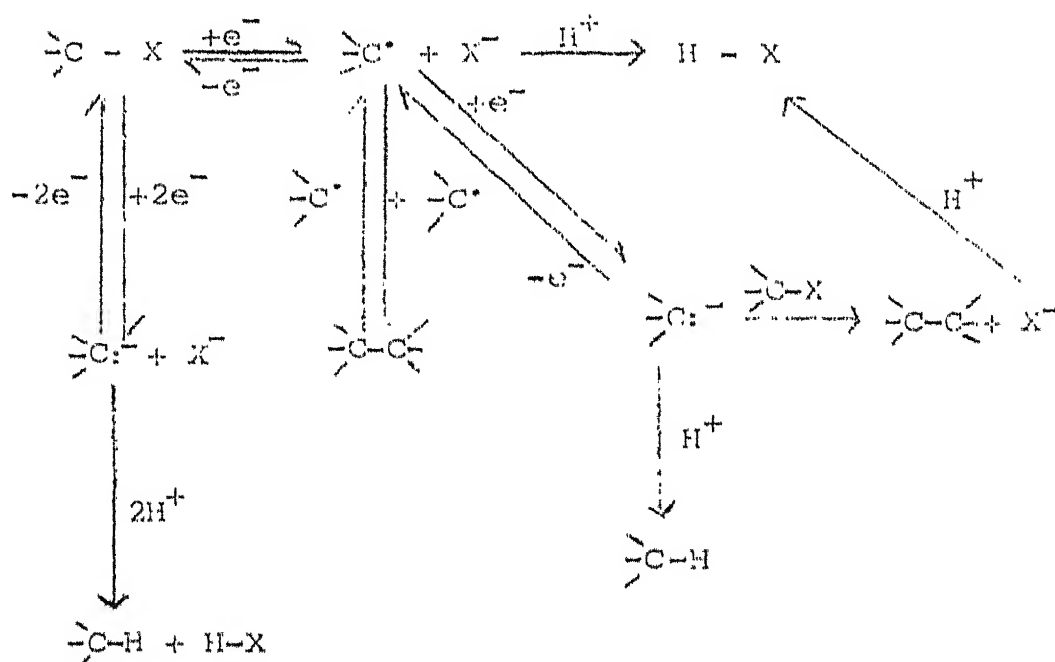
SCHEME I.3



Similar reactions with dianions of thio carbonyl compounds¹¹⁶ and olefins^{117,118} are also known to occur.

A possible mechanistic sequence for reductive cleavage of compounds of the type $\text{>C} - \text{X}$, where $\text{X} = \text{OH}$, OR , ONO_2 , CR_3 , SR or a halogen by alkali metal/solvent is outlined in Scheme I.4.

SCHEME I.4

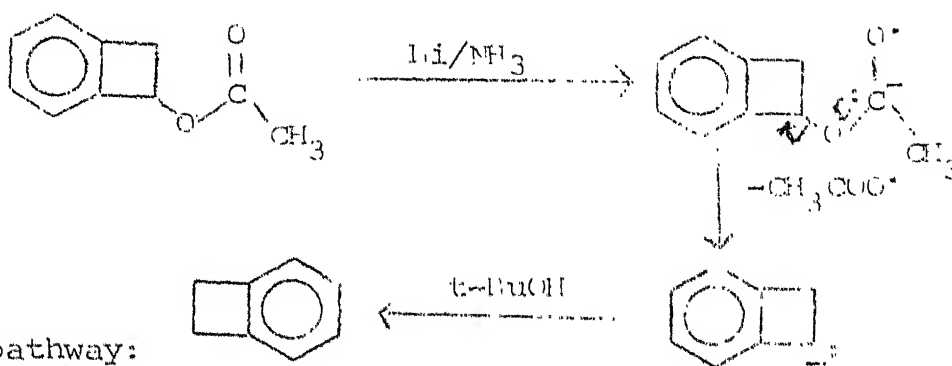


Recent reports on the reductive cleavage of $\text{C}-\text{O}$ ¹¹⁹, $\text{C}-\text{C}$ ¹¹⁹⁻¹²¹, $\text{C}-\text{Cl}$ ¹²² and $\text{C}-\text{S}$ ¹²³ bonds are in conformity with the above mechanism.

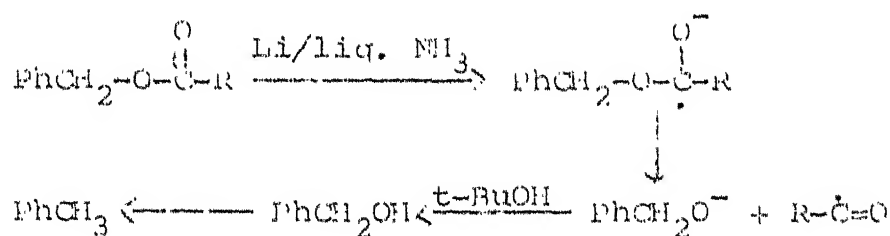
Esters also undergo cleavage via electron transfer. Thus, Li/liq. NH_3 affects the cleavage of esters,^{120a,125} by one of the two pathways exemplified in Scheme I.5.

SCHEME I.5

1st pathway:

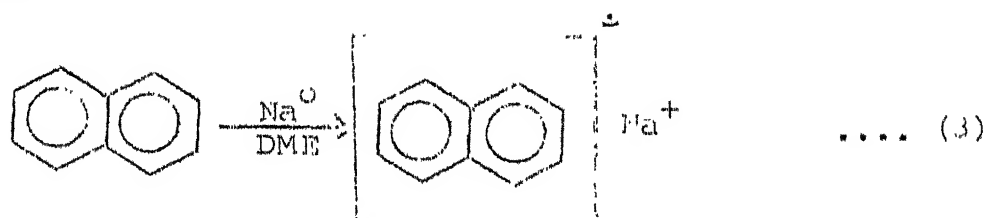


2nd pathway:



Reactions of Radical-Anions of Aromatic Hydrocarbons

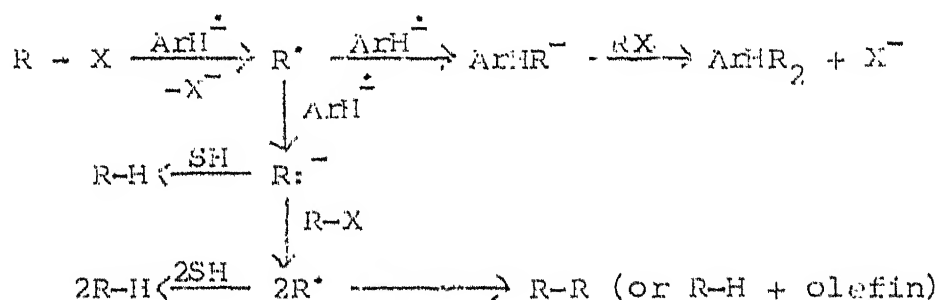
In numerous electron transfer reactions, radical-anions of aromatic hydrocarbons act as a potential source of electrons. Thus, reduction of naphthalene¹²⁹ by sodium yields sodium naphthalene (Eqn. 3):



These radical-anions can either act as strong bases and abstract protons from weakly acidic substrates or transfer a single electron to appropriate substrates.

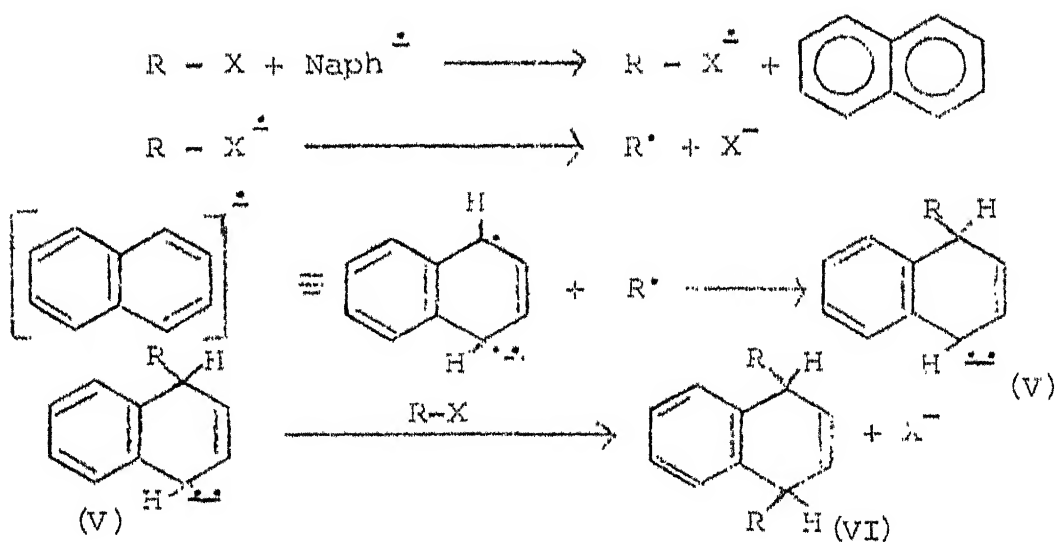
Reactions of alkyl halides with radical-anions have been thoroughly investigated and reviewed.¹³⁰⁻¹³² The general mechanism of these reactions is outlined in Scheme I.6.

SCHEME I.6

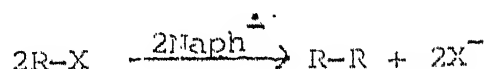


Alkylation of aromatic nucleus proceeds by coupling of alkyl radicals with aromatic radical-anions. For example, reaction of sodium naphthalene with R-X first produces anion(V) which by subsequent S_N2 displacement on the alkyl halide gives dialkylate(VI) as shown in Scheme I.7.

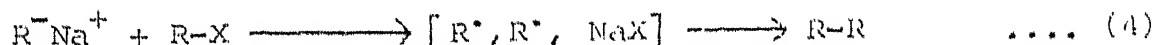
SCHEME I.7



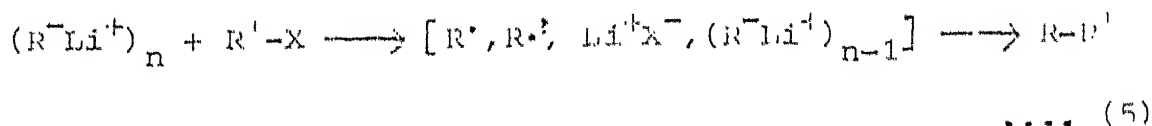
Of various reactions of alkyl halides, reductive dimerization is least understood:



Both radicals¹³⁵ and anions¹³⁴ are proposed as intermediates in the formation of dimers. The most acceptable explanation for the rapid rate of alkyl dimer formation is the coupling of geminate radical pairs¹³⁴ as shown in Eqn. 4:



In this respect, the course of the above reaction is parallel to that of alkyl lithiums with alkyl halides (Eqn. 5):



The radical pairs generated by electron transfer from alkyl-lithium in solvent cage, may couple, disproportionate or diffuse apart.

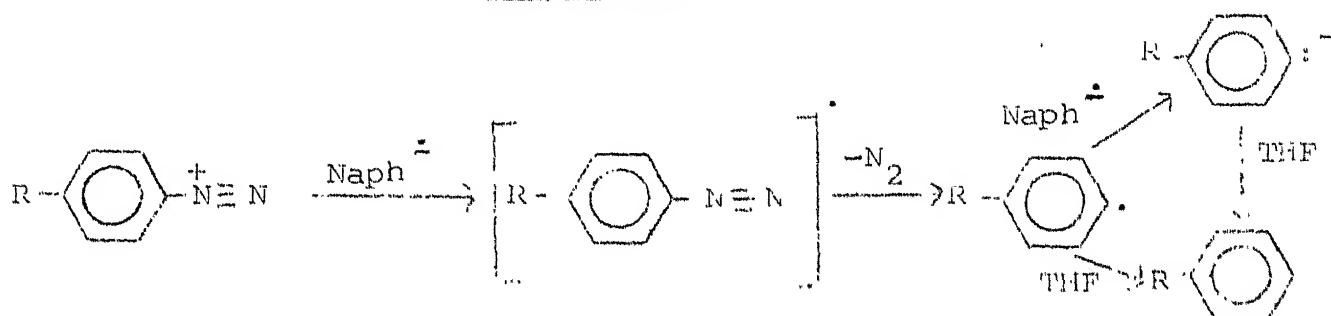
The intermediate radicals formed in this reaction have been trapped¹³⁶ and also detected by ESR spectroscopy.^{137,138}

Dimerization has also been observed in the reduction of alkyl halides with metal complexes.¹³⁹ Cyclopropyl halides are also reduced by alkali metal naphthalenes.¹⁴⁰

Singh and coworkers^{149a} have proposed a $\pi^* \rightarrow \pi^*$ electron transfer mechanism involving the intervention of aryl-radicals in

the dediazonation of arenediazonium salts with sodium naphthalene (Scheme I.8):

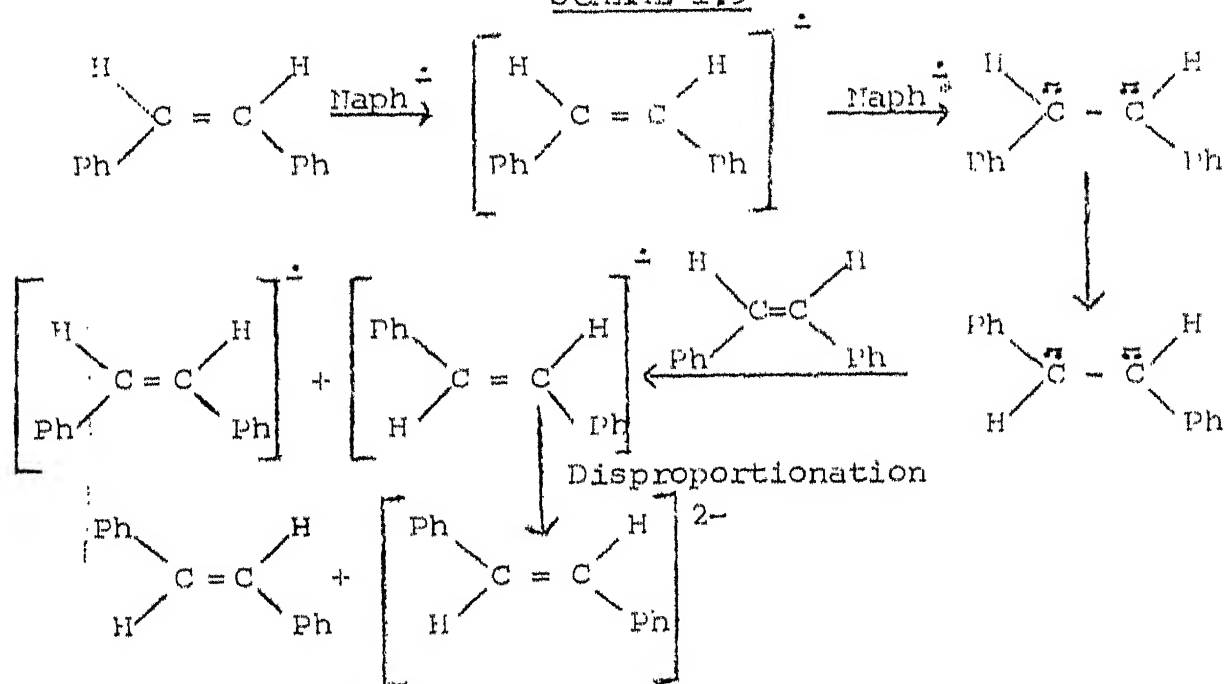
SCHEME I.8



Sodium naphthalene also reacts with phenylacetonitrile,¹⁵⁰⁻¹⁵¹ giving a mixture of products.

Isomerization^{149b,c} of *Z*-stilbene to *E*-stilbene via the dianion is induced by sodium naphthalene as shown in Scheme I.9.

SCHEME I.9



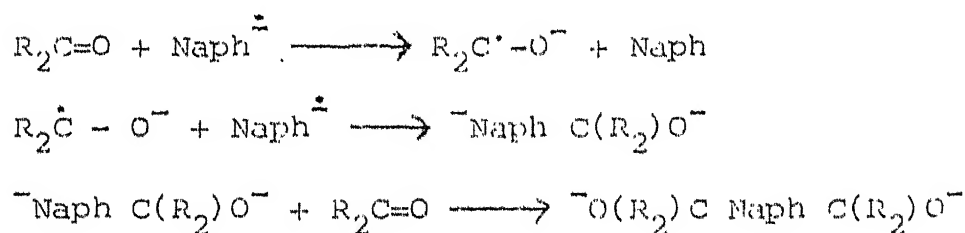
Reductive cleavage of esters by sodium naphthalene has also been reported recently.^{122,153}

Two alternative mechanisms, one involving dianion intermediates and the other free radicals, in the reaction of aliphatic and aromatic ketones with sodium naphthalene have been proposed by Holy and coworkers.¹⁵⁴ (Scheme I.10):

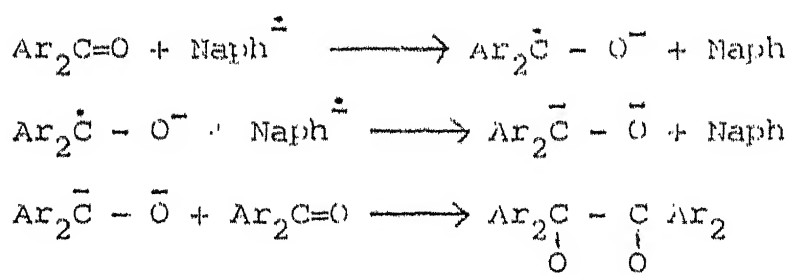
SCHEME I.10

(A) Dianion Mechanism:

(i) Aliphatic carbonyl compounds:

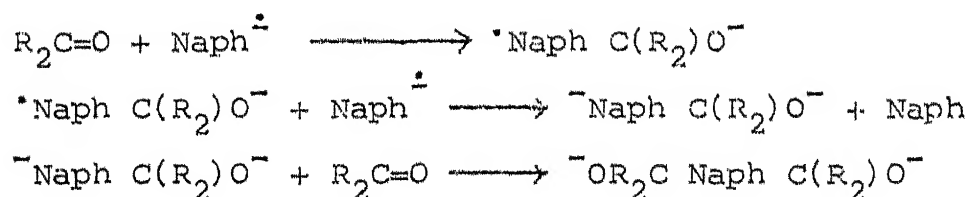


(ii) Aromatic carbonyl compounds:

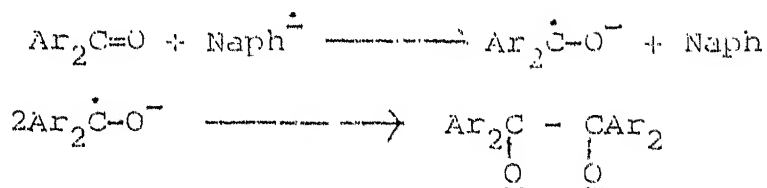


(B) Radical Mechanism:

(i) Aliphatic carbonyl compounds:



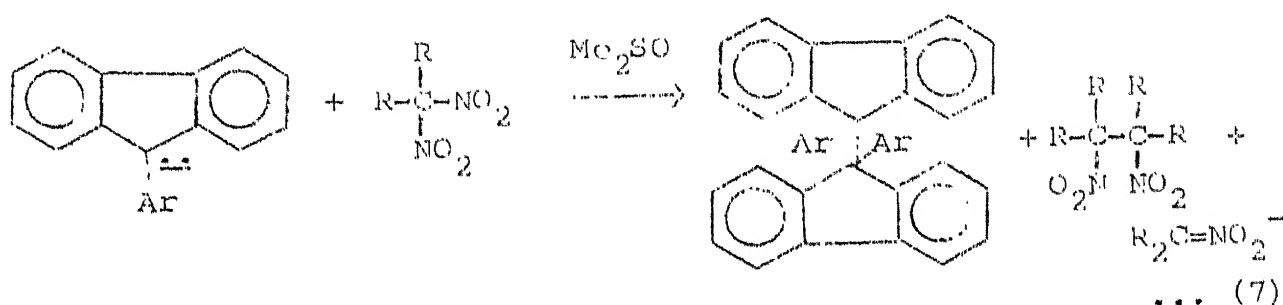
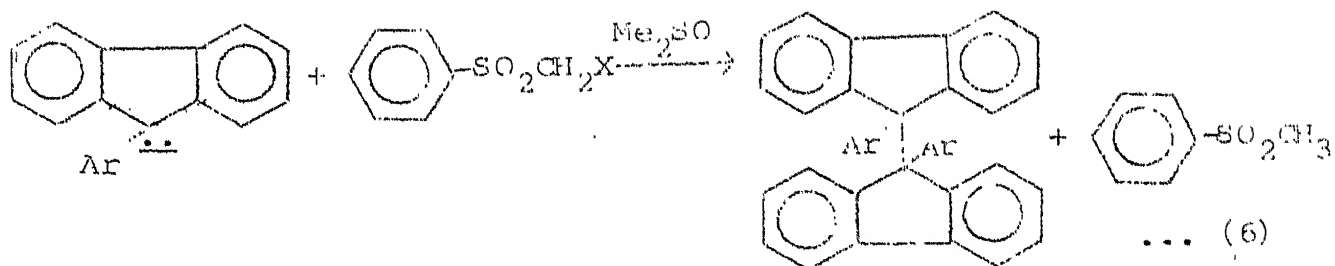
(ii) Aromatic carbonyl compounds:



Sodium naphthalene also reacts with molecular hydrogen,¹⁵⁵ sulfur dioxide,¹⁵⁶ carbon dioxide,¹⁵⁷ aryl halosilanes¹⁵⁸ and aryl phosphates.¹⁵⁹ Naphthalene radical-anions have been effectively used to initiate polymerization reactions¹⁶⁰⁻¹⁶¹ and in the fixation of molecular nitrogen.¹⁶²

Reactions involving electron transfer from thiophenoxide^{31a, 163-165} and alkoxide¹⁶⁶ anions have also been reported. An electron transfer from a donor reagent is feasible only when the substrate has sufficiently high electron affinity. This explains the successful oxidation of even poor donors like alkoxides¹⁶⁸ by aromatic nitro compounds and the inability of butyl lithium¹⁶⁷ to add to tetraphenyl ethylene or 1,1,3,3-tetraphenyl but-1-ene.

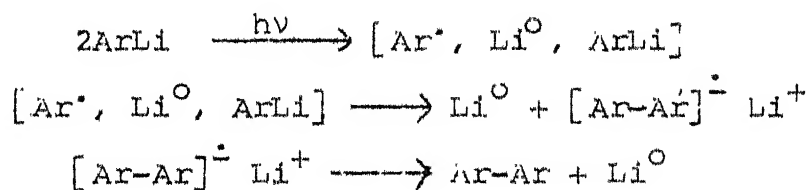
Single electron transfer has been proposed in the reactions of 9-aryl fluorenyl anions with phenyl halomethyl sulfones and dinitro compounds¹⁶⁹ (Eqns. 6 and 7) recently by van Tamlen and coworkers.¹⁷²



That strong bases¹⁶⁹ give up electrons more easily was demonstrated by means of the straight line Bronstead correlations of the pK_a 's of the fluorenyl system vs. the observed rates of these reactions.

Biphenyl radical-anion has been proposed by van Tamelen and coworkers¹⁷² to be the intermediate species in the photolysis of phenyl lithium (Scheme I.11):

SCHEME I.11

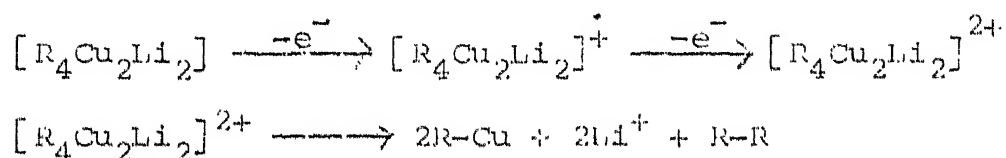


Organolithium compounds are known to donate electrons to aromatic hydrocarbons,¹⁷⁰ oxygen⁷⁹ and peroxides.¹⁷¹

Addition of lithium organocuprates to unsaturated carbonyl compounds by electron transfer mechanism has been proposed by

H.O. House.¹⁷³ A two-electron transfer oxidation pathway for oxidation of lithium organocuprates by O_2 , $PhNO_2$ or $Cu(II)$ has been proposed as shown in Scheme I.12.

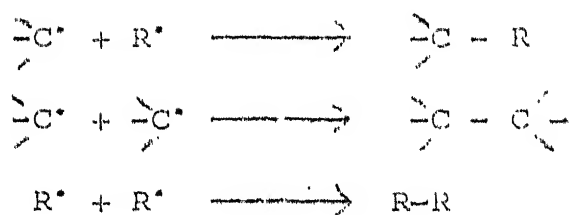
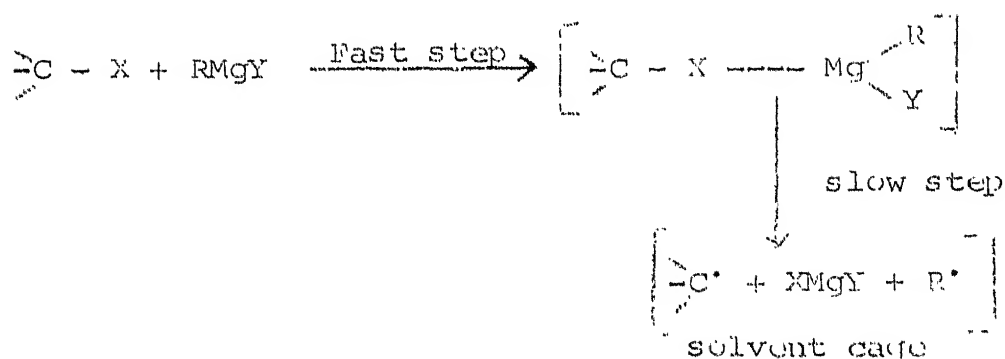
SCHEME I.12



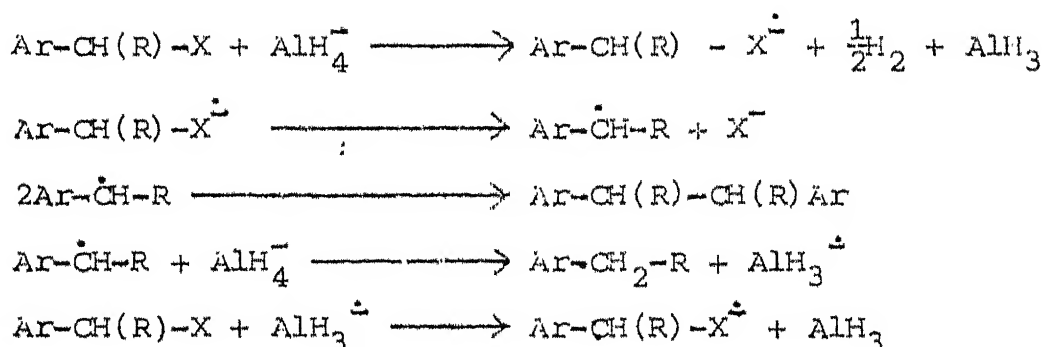
A single electron transfer pathway has also been proposed for the reaction of lithium 1,1-di-methylallene with benzyl chloride¹⁷⁴ and ketones.¹⁷⁵ Lithium 1,1-dimethylallene has been prepared by the reaction of 1,1-dimethylallene with lithium tetramethyl piperidine.

Several metal hydrides (e.g., $LiAlH_4$, AlH_3 , MgH_2 etc.) reduce ketones,¹⁸⁴ polynuclear aromatics,¹⁸⁵ bromophenylallyl ether¹⁸⁶ and alkyl halides¹⁸⁷ by a single electron transfer process. Lithium tetrakis(N-dihydropyridyl)aluminate (LDPA) has also been found to give similar results.¹⁸⁸ Grignard reagents have also been reported to transfer electron to oxygen,¹⁶⁹ ketones,^{14-16,19,180-182} alkyl halides²² and non-benzenoid aromatic compounds. Similar reaction occurs with dialkyl magnesium compounds.¹⁷⁷⁻¹⁷⁹

Singh and coworkers²² have proposed electron transfer as the first step in the reaction of Grignard reagents with benzylic halides as shown in Scheme I.13.

SCHEME I.13

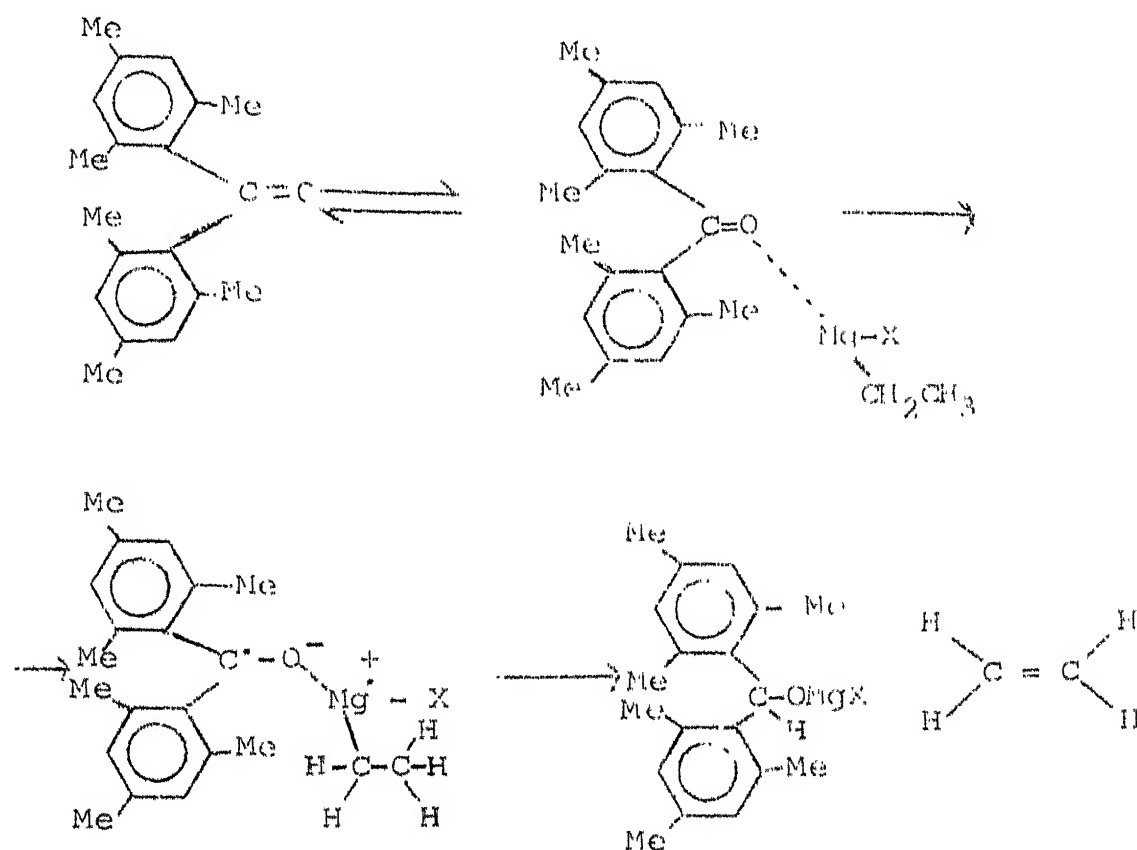
Reactions of (9-anthryl)-aryl methyl chlorides with organomagnesium and lithium reagents have been shown to proceed via single electron transfer pathways.¹⁸³ A new electron transfer mechanism has been proposed by Singh et al.¹⁸⁹ in the lithium aluminium hydride reduction of certain benzylic halides and 1-2-chlorostilbene.¹⁹⁰ The mechanism of reduction of benzylic halides is outlined in Scheme I.14:

SCHEME I.14

The halide ion, X^- , formed in step 2 combines with AlH_3 giving AlH_3X^- . This anion either acts as a source of hydrogen atoms or donates an electron as an inferior alternative to AlH_4^- . Similarly, anions $AlH_2X_2^-$ and $AlHX_3^-$ formed during the reaction can donate hydrogen atoms or electrons as inferior alternatives to corresponding anions with lesser number of halogen atoms (X) attached to the central aluminium atom.

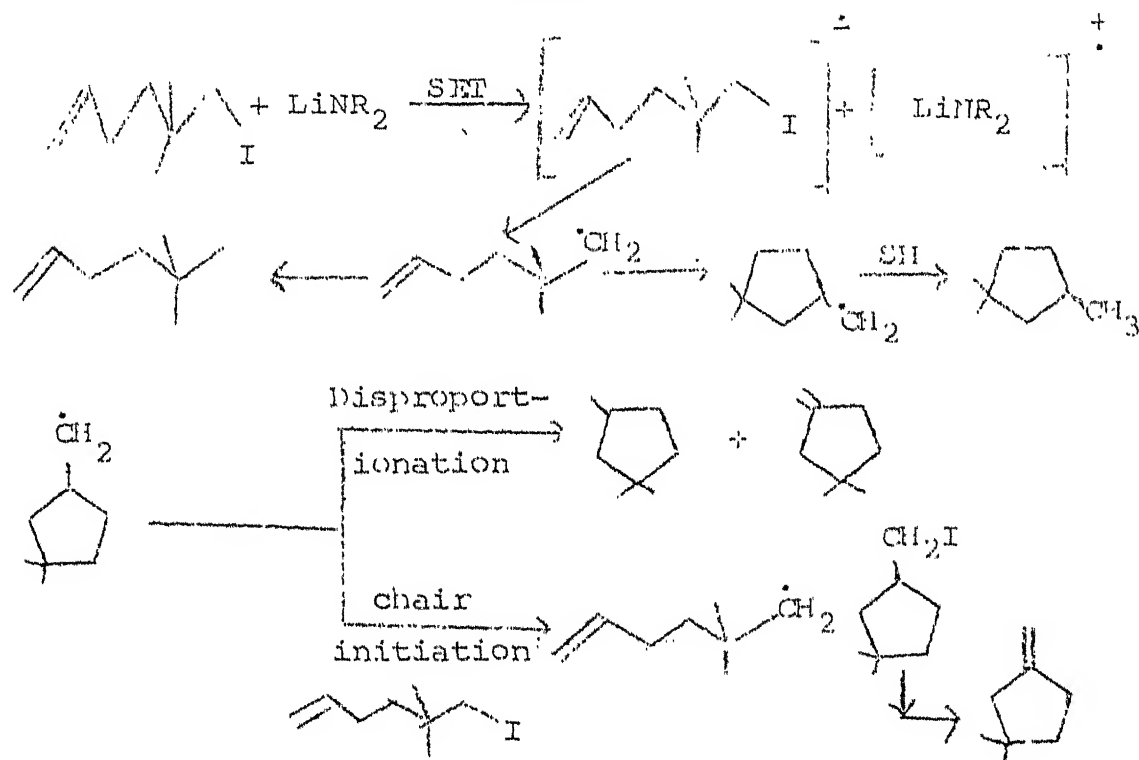
Sterically hindered ketones are reduced to alcohols via SKT process as shown below in Scheme I.15:

SCHEME I.15



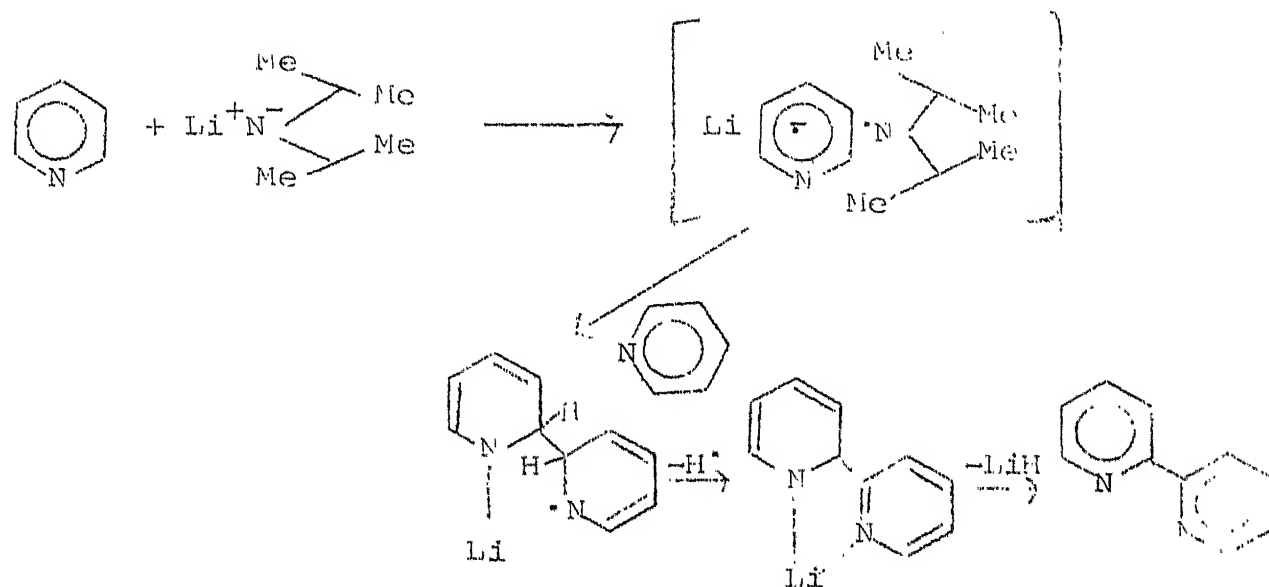
Reduction of alkyl iodides with lithium diisopropylamide proceeds via single electron transfer process outlined in Scheme I.16.

SCHEME I.16

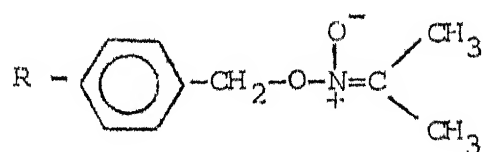


Reduction of ketones, alkyl halides and polynuclear aromatics by alkali metal amides and alkoxides have been shown by Ashby and coworkers^{191a,b} to proceed via SET pathway. SET pathway has also been demonstrated in the reaction of lithium diisopropylamide with π -deficient heteroaromatics.¹⁹² The proposed mechanism is outlined in Scheme I.17:

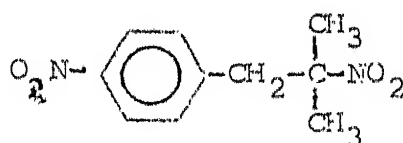
SCHEME I.17



In 1949, it was observed by Bender and Hass¹⁹³, that while p-substituted benzyl chlorides, $\text{p-R-C}_6\text{H}_4\text{CH}_2\text{Cl}$ ($\text{R}=\text{CN}$, CF_3^+ , $^+\text{N}(\text{CH}_3)_3$, COCH_3 , COOCH_3 , CH_3 or Br) on treatment with 2-nitropropanate anion yield O-alkylated products, p-nitrobenzyl chloride yields predominantly the C-alkylated product. Later, it was found that the ratio of the C- and O-alkylated products depends also on the nature of the leaving group X in the p-nitrobenzyl system $\text{p-O}_2\text{NC}_6\text{H}_4\text{CH}_2\text{X}$.¹⁹⁴



O-alkylated product



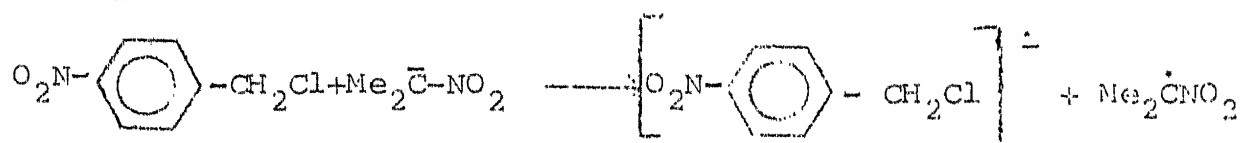
C-alkylated product

While the iodide and bromide predominantly give O-alkylated products, the chloride preferentially yields the C-alkylated product. On the basis of these observations and other detailed

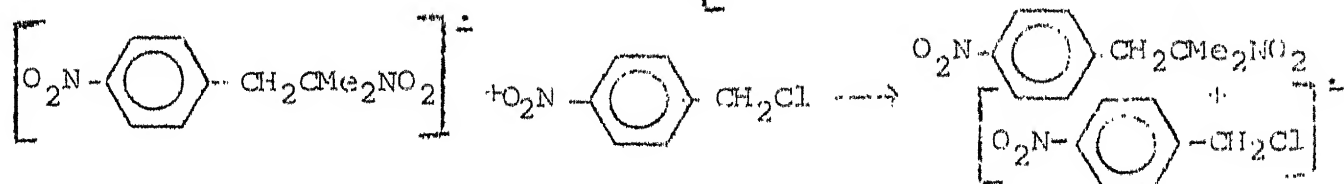
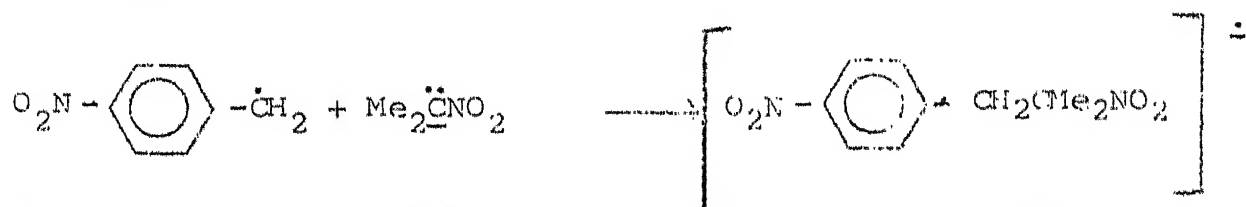
studies, it was proposed that O-alkylation proceeds by the usual S_N2 displacement process, while C-alkylation occurs by means of an electron transfer process, in which radical anions and free radicals are important intermediates.^{195,196}

The mechanism for the C-alkylation reaction proposed independently in 1966 by Kornblum et al.^{197,198} and Russell et al.^{199,200} is outlined below:

Initiation:



Propagation:

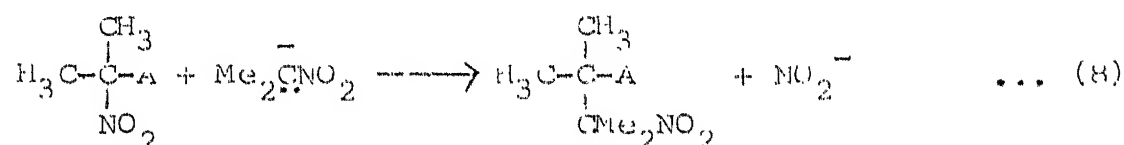


The radical chain nature of this mechanism was established on the basis of the observation that these reactions are inhibited by oxygen²⁰¹ and p-dinitrobenzene²⁰² and accelerated by light.^{201,203}

A similar mechanism, designated as $S_{RN}1$, was later proposed by Kim and Bunnet²²⁴ for aromatic systems. Aliphatic $S_{RN}1$ substitution

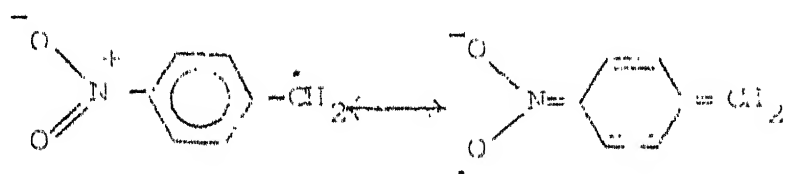
also takes place at tertiary carbon atoms of p-nitrocumyl chloride²⁰⁴, α-p-dinitrocumene,²⁰⁵⁻²⁰⁸ m-nitrocumyl chloride²⁰⁹ and α,m-dinitrocumene²⁰⁹ with various nucleophiles.

Purely aliphatic compounds also undergo nucleophilic substitution with 2-nitropropanate anions.^{208, 211, 212} (Eqn.8) :



(A = COOEt, CPh, CN, NO₂)

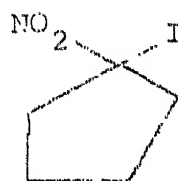
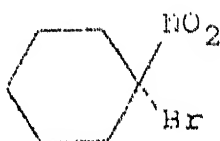
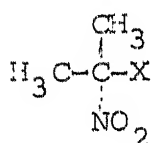
Oxanion nucleophiles occasionally combine with radicals of p-nitrobenzyl type in the course of aliphatic S_{RN}1 reactions. Kornblum^{210a} has suggested with reference to canonical forms such as:



that such steps can be considered as Michael-type attachments of nucleophiles to unsaturated systems. The filled outer shell orbital of the nucleophile interacts with a π-orbital at the benzylic radical site. For tertiary and secondary benzylic systems, Kornblum^{210b} has proposed that the initially formed nitronic esters rearranges to yield more stable C-alkylated products. That the coupling between p-nitrobenzylic radicals and

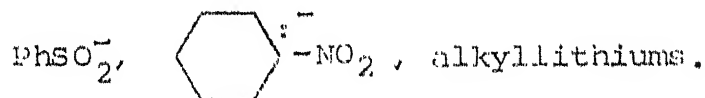
aci-nitronate ions is dependent on steric factors was demonstrated by Norris et. al.²²² Branching at the carbon which is placed α - to the reaction site causes a shift in product distribution towards O-alkylation and away from C-alkylation. The association step has been proposed to be a kinetically controlled irreversible process.

α -Halonitro compounds of the types shown below, on treatment with nucleophiles, undergo substitution in which the halogen rather than the nitro group is displaced.²¹³⁻²¹⁷



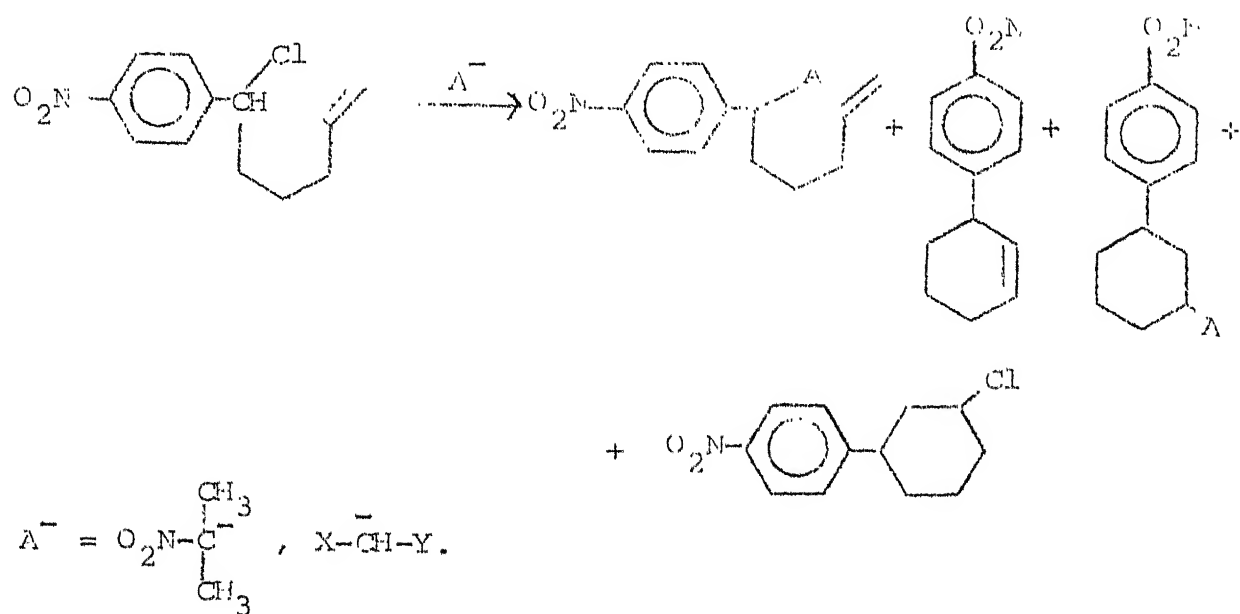
X = Cl, Br, I

Nucleophiles: $\text{Me}_2\ddot{\text{C}}\text{NO}_2^-$, $\text{Et}\ddot{\text{C}}(\text{COOEt})_2^-$, $\text{Me}(\text{CN})\ddot{\text{C}}(\text{COOEt})^-$.



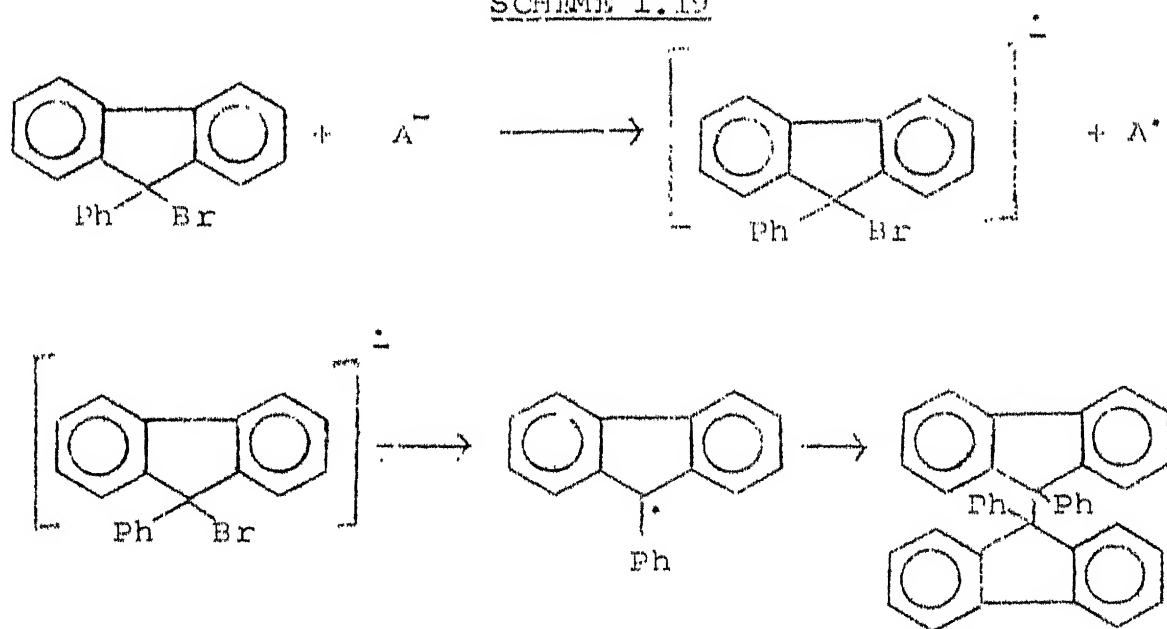
$\text{S}_{\text{RN}}1$ mechanism is also found to operate in the reactions of α -nitro sulfides with nitronate, malonate and sulfinate anions.^{216a} Intramolecular cyclization using appropriately substituted p-nitrobenzyl chloride²¹⁸ has been achieved (Scheme I.18):

SCHEME I.18

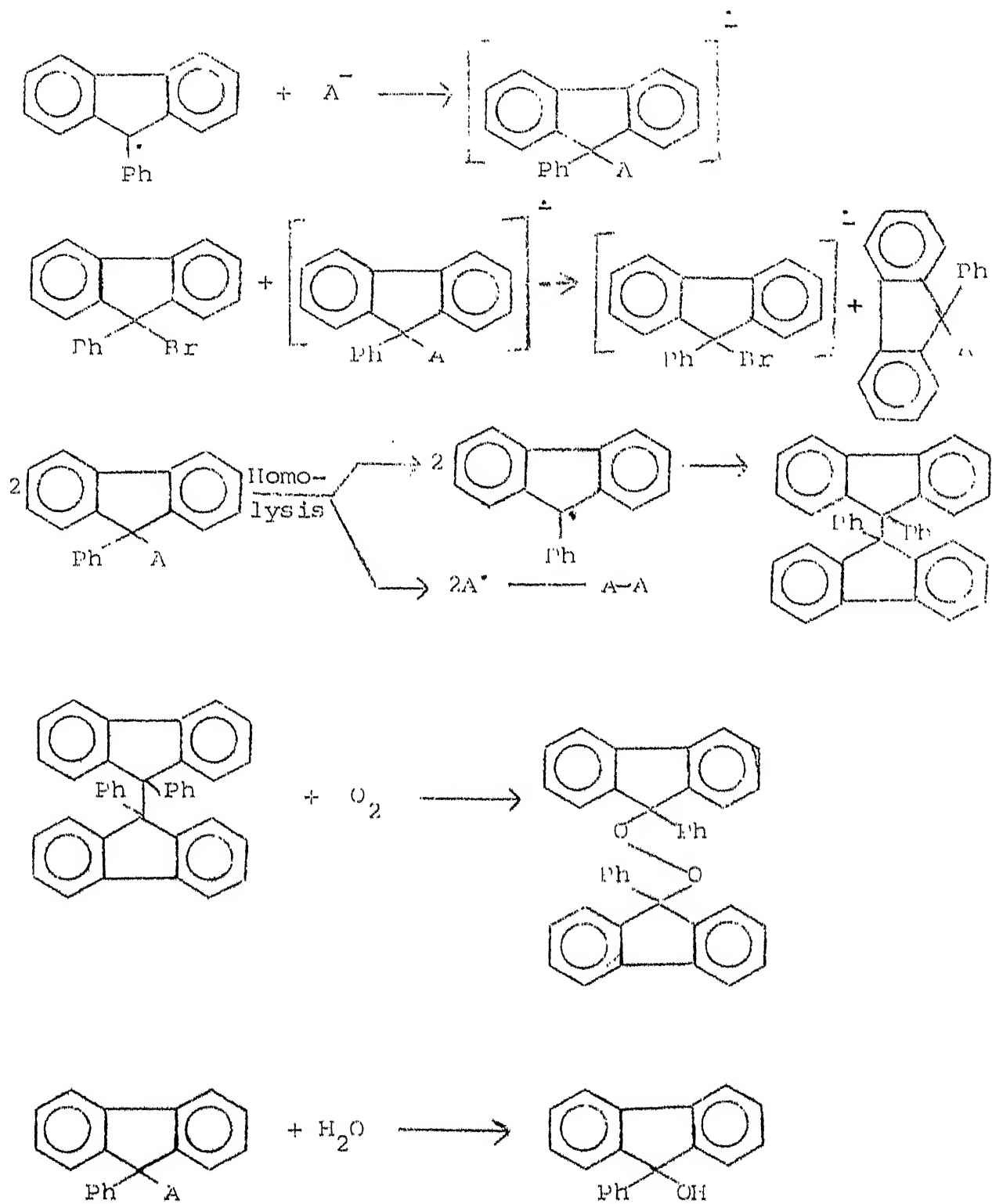


An electron transfer radical-anion mechanism outlined in Scheme I.19 has been proposed by Singh et.al.^{31a} for the reactions of 9-bromo-9-phenyl fluorene with certain nucleophiles (Scheme I.19).

SCHEME I.19



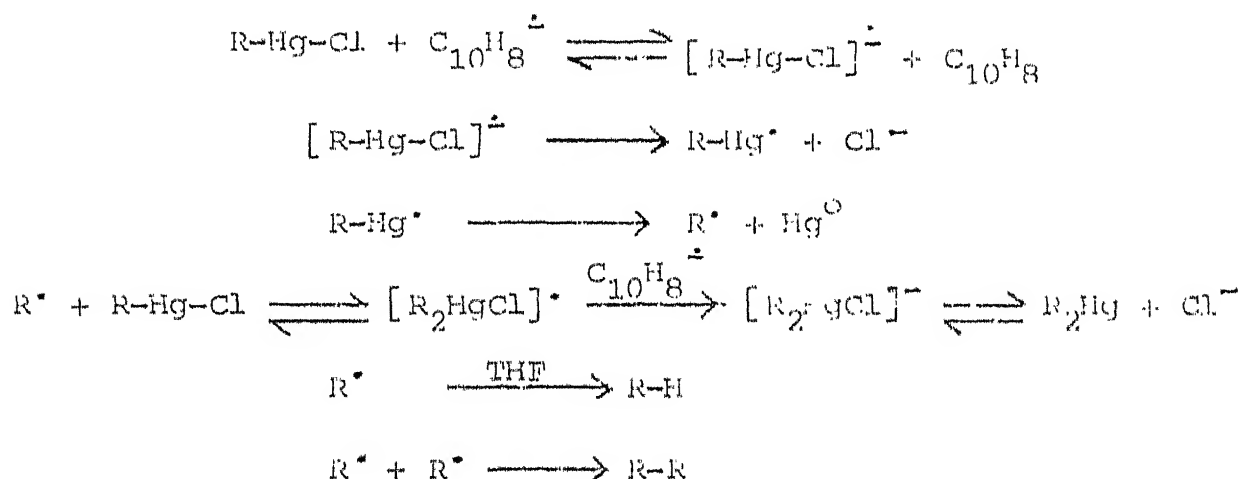
..contd.



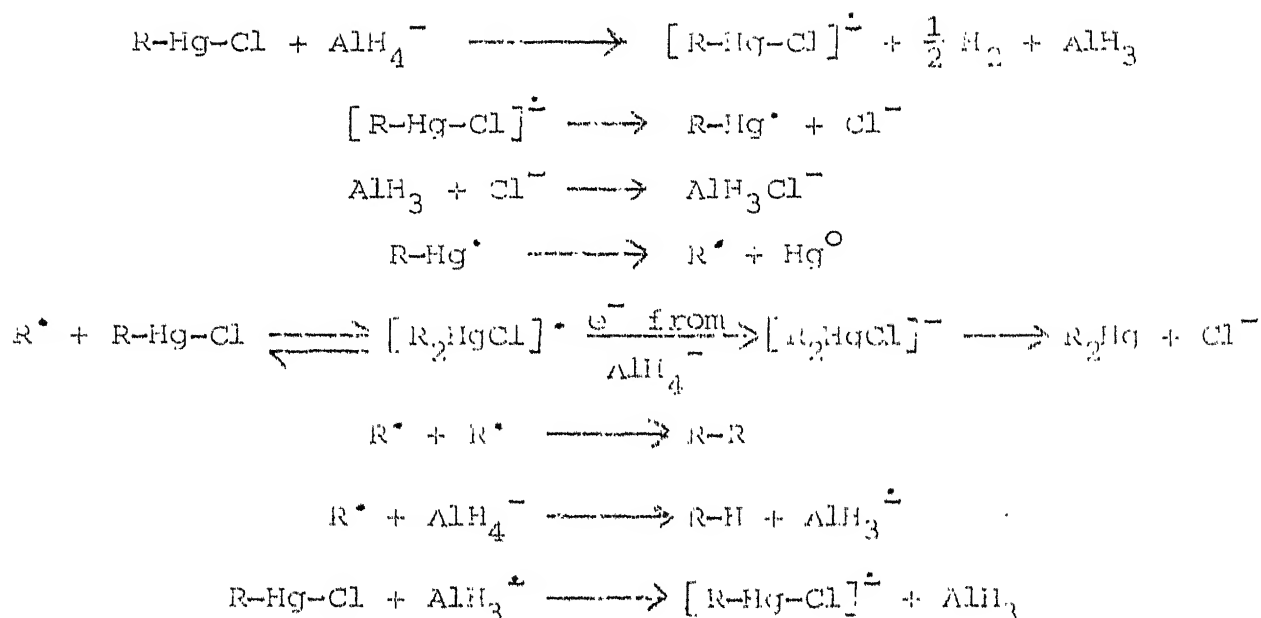
Where A = PhS, I.

Russell et.al. have reported that organomercuric halides react with 2-nitropropanate anion,^{219a} dialkyl phosphite anions^{219b} and sulfinate anions²²⁰ by $S_{RN}1$ pathways. Reaction of N-(p-nitrobenzyl)pyridinium cation with 2-nitropropanate anion²²¹ has also been reported. Singh et al.^{146a} have proposed an electron transfer free-radical mechanism involving a $\pi^* \rightarrow \pi^*$ electron transfer from naphthalene radical anion to organomercuric halides yielding hydrocarbon, dimer and diorganomercury compounds Scheme I.20.

SCHEME I.20

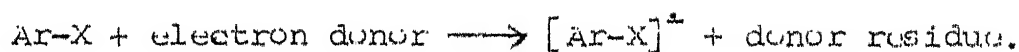


Similar reaction with LiAlH_4 (Scheme I.21) has also been proposed by Singh and coworkers.^{146b} Symmetrization of the aryl mercuric halides has been observed by these workers for the first time. Further reduction of these diorganomercurials, though relatively slowly has also been observed.

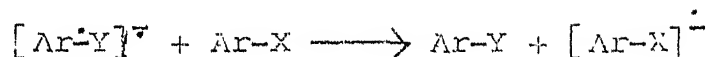
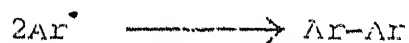
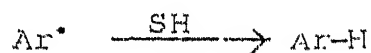
SCHEME I.21

B. Bigot et al.²²³ have reported a theoretical ab initio study of $\text{S}_{\text{RN}}1$ mechanism. According to them, the driving force for electron transfer in the initiation step is the spontaneous dissociation of the radical-anion formed and that the propagation rate of the chain mechanism may be determined better by diffusion phenomena rather than by energetic considerations.

The aromatic Radical Nucleophilic Substitution ($\text{S}_{\text{RN}}1$) mechanism (Scheme I.22) may be generalized as follows.²²⁴

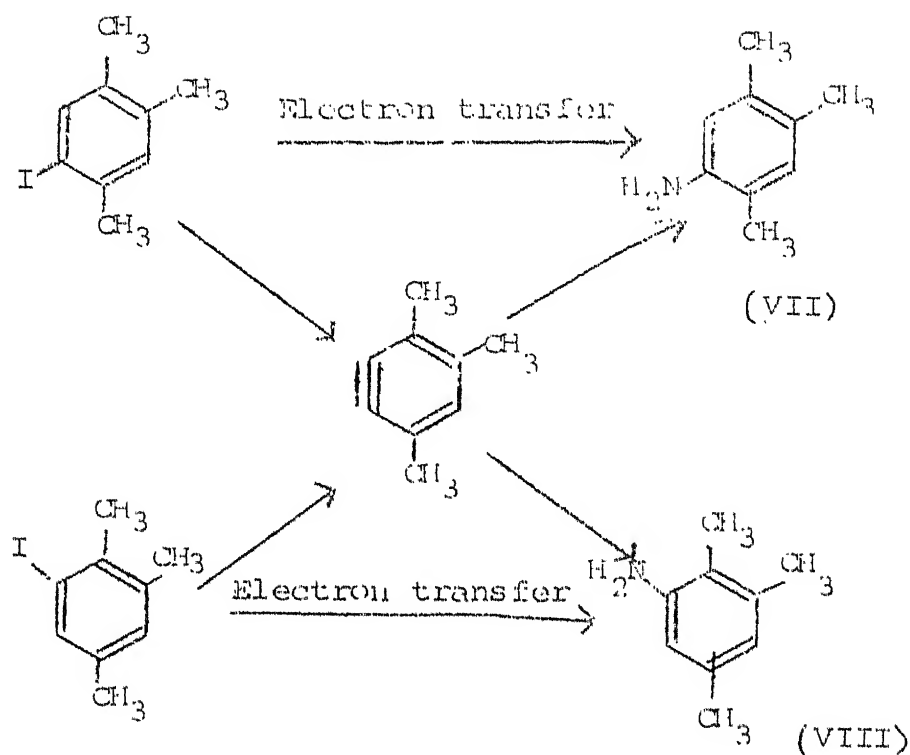
SCHEME I.22Initiation:

... contd.

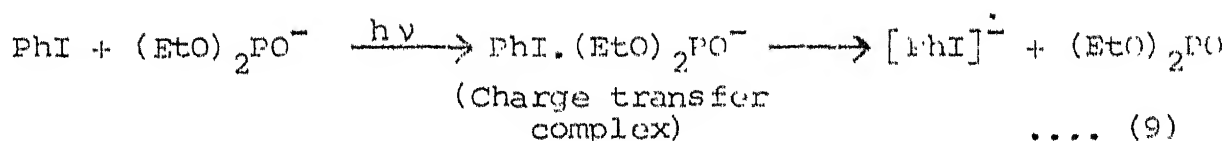
Propagation:Termination:

The overall reaction scheme is analogous to that proposed by Kornblum¹⁹⁷ and Russell¹⁹⁹ for substitution in aliphatic systems.

The aromatic $S_{\text{RN}}1$ mechanism was postulated for the first time in order to account for the results of the reaction of aryl halides with amide ion in liquid ammonia.²²⁴ The ratio of the two products VII:VIII, in the reactions of 5- and 6-iodopseudocumenes with KNH_2 in liquid ammonia, was found to be dependent on the position of the iodine atom in the starting halide. Aryne intermediates, if postulated, would yield, in these reactions, the two products in the same ratio. This fact coupled with the observed catalysis by light and inhibition of the substitution reaction by tetraphenyl hydrazine suggests the occurrence of the following radical chain mechanism in these reactions:

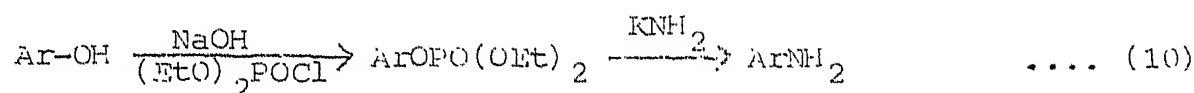


Most aromatic $S_{RN}1$ reactions are initiated either chemically by solvated electrons from alkali metals,²²⁵ electrolytically²²⁶ or photochemically.^{225, 227} Though the exact nature of the photo-initiated process is not known with certainty, evidence in favour of electron transfer occurring through the formation of an intermediate charge transfer complex has been presented (Eqn.9):



Facile displacement of SPh ,²²⁹ NMe_3^+ ²²⁹ and $\text{OPO}(\text{OEt})_2$ ²²⁹⁻²³¹ by some other groups via $S_{RN}1$ mechanism has great synthetic utility.

Thus, Ar-OH can be converted into Ar-NH₂ in good yields²³⁰ under mild conditions (Eqn.10) :



The initiation mechanism of the reactions occurring in dark^{224, 228} without addition of electron-donating initiators (the so called autoinitiated reactions) is obscure. Here, a reasonable possibility^{197, 198} is a thermally activated electron transfer from the nucleophile to the substrate.

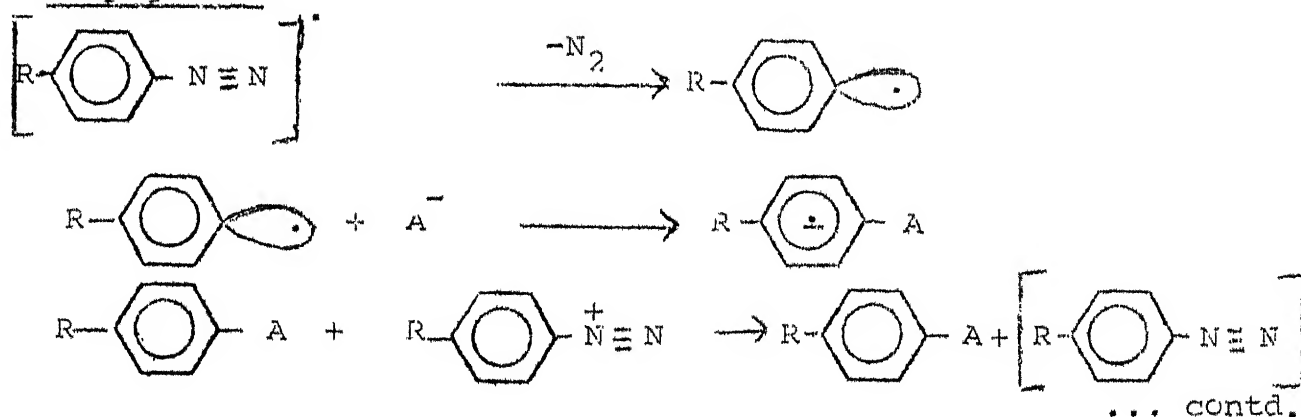
Singh et al.^{165, 237} have proposed a mechanism similar to the aromatic S_{RN}1 mechanism for the reactions of arenediazonium salts with various nucleophiles as shown in Scheme I.23.

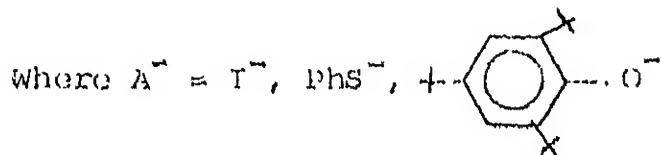
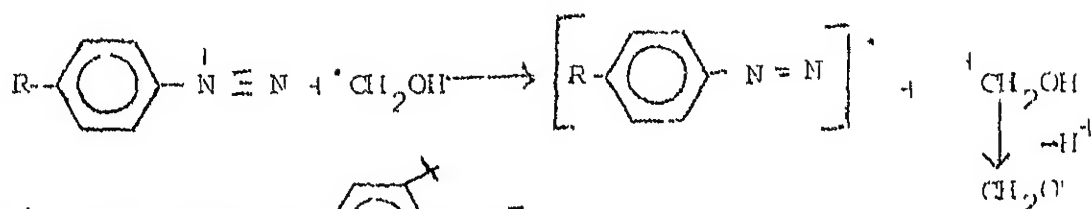
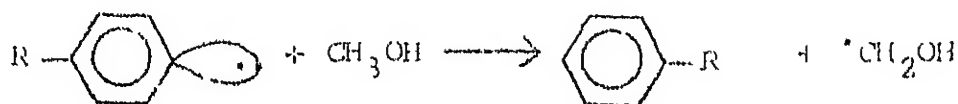
SCHEME I.23

Initiation:



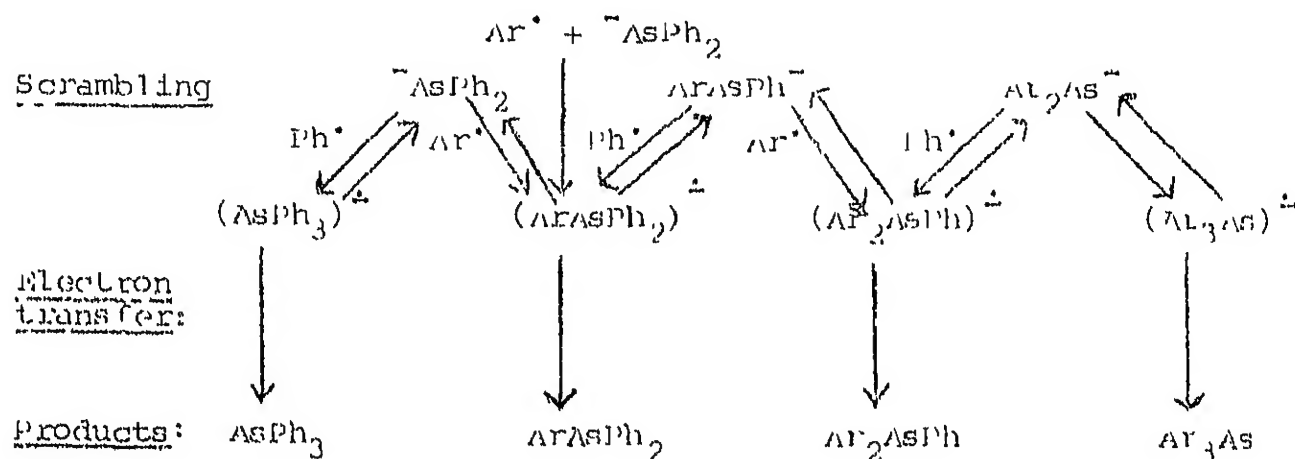
Propagation:



Termination:

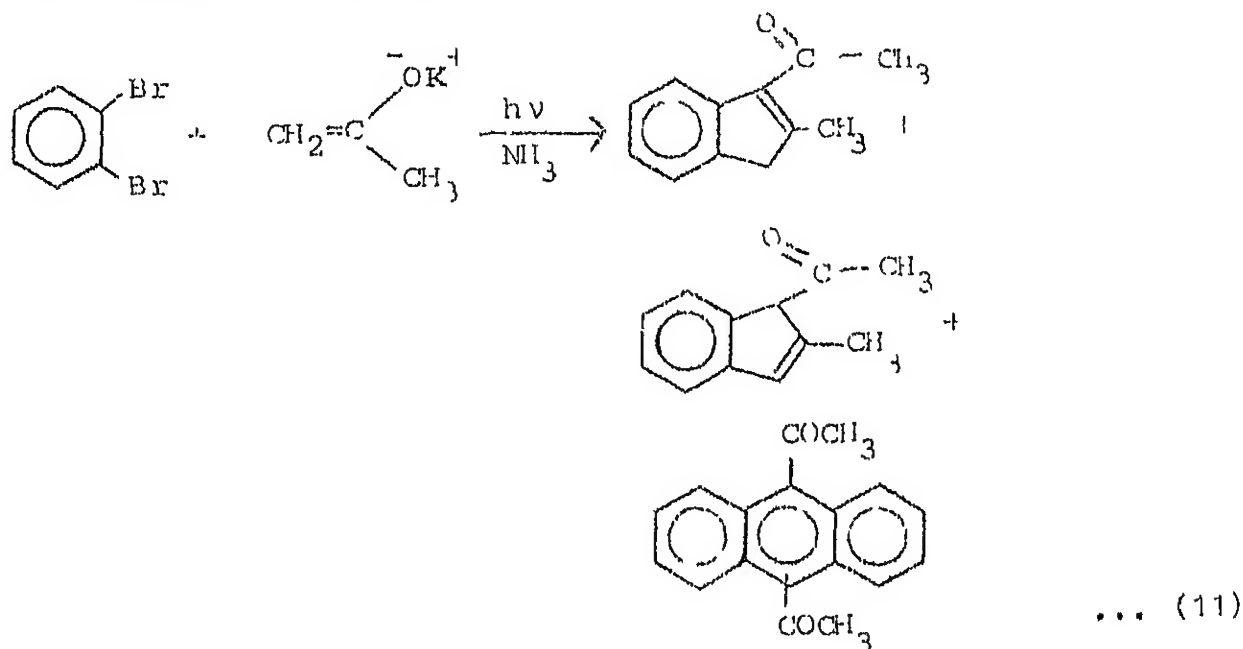
Apart from the nucleofugic group, nitro and hydroxy groups,^{232, 233} interfere with $\text{S}_{\text{RN}}1$ processes. Steric hindrance has no noticeable effects in these reactions.²³⁴ Bunnet²³⁸ has recently showed that the nucleophilic reactivities differ in aromatic $\text{S}_{\text{RN}}1$ reactions by not more than a factor of 10. He reasoned that this is due to combination of aryl radical with nucleophiles occurring at encounter-controlled rates.

Photostimulated reactions of haloaromatic compounds with potassium diphenylarsenide and potassium diphenylstibide in liquid NH_3 have been reported by Rossi et al.²³⁶ These workers have suggested that in the process of coupling of an aryl radical with a nucleophile, σ and σ^* MO's are formed, and in case the σ^* MO's of the aryl-As bonds are the lowest energy MO's of the system, scrambling of the aryl rings is observed as presented in Scheme I.24.

SCHEME 1.24Starting reaction:

On the other hand, if the π^* MO of the aryl moiety is lower in energy than the σ^* MOs of the aryl-As bonds, as the aryl radical couples with the nucleophile, a σ^* MO is formed with the odd electron and by intramolecular electron transfer to the π^* MO, a σ^\wedge radical-anion is formed and only the straight forward substitution product is obtained. Theoretical considerations confirm that the σ^* MO energy of the phenyl-As bond is lower than the π^* MO energy of naphthyl and phenanthryl moieties, thus leading to scrambling of aryl rings. On the other hand, the π^* MO energy of quinoline is lower than the σ^* MO energy of the phenyl-As bond, resulting in the substitution product.

Aromatic $S_{RN}1$ reactions have been used to synthesize indoles,²³⁹ benzo-[b]-furanes,²⁴⁰ 2-substituted indoles²⁴¹ and acetyl-methylidines.²⁴² For example, see Eqn. 11 below:

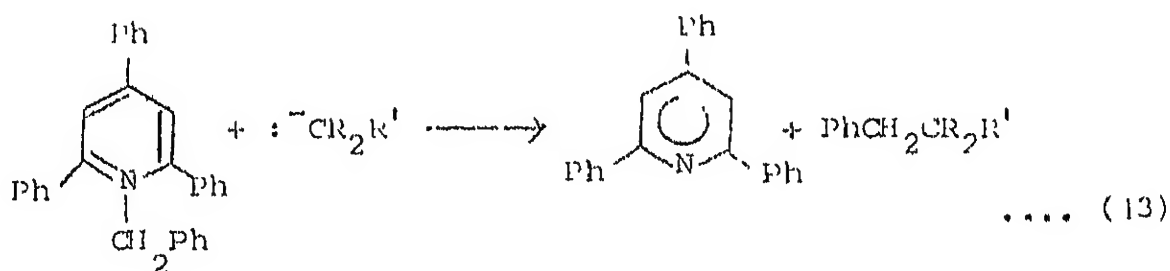


An alternative mechanistic possibility to the propagation cycle of $S_{RN}1$ mechanism has been presented and dubbed $S_{RN}2$.²³⁵ Its characteristic feature is that the nucleophile brings about direct displacement of the nucleofugal group from radical-anion $[Ar-X]^{\cdot-}$ as shown in Eqn. 12:

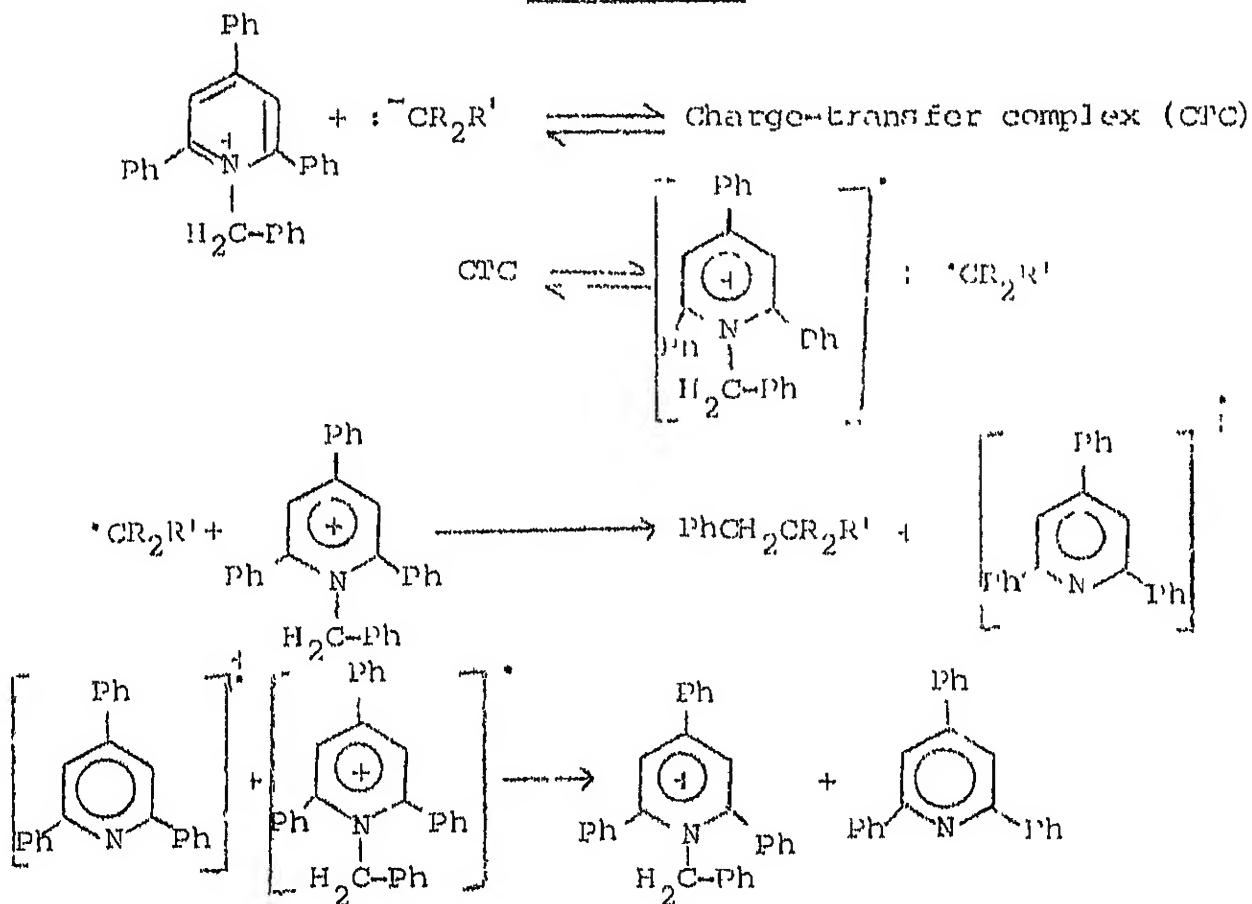


According to this mechanism, the relative nucleophilic reactivity with various substrates should depend on the leaving group; but recently, Bunnett et al.²³⁸ have shown that such a condition is not necessary.

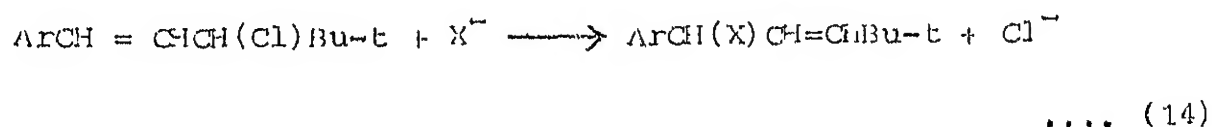
Reaction of 1-alkylpyridinium cation with anions derived from nitroalkane and ethylmalonate was proposed to occur via a non-chain radical pathway²⁴³ (Eqn. 13); but Katritzky and coworkers²⁴³ have proposed that these nucleophilic substitution reactions occur via radical intermediates as shown in Scheme I.25.



SCHEME I.25



The reaction represented by Equ. 14 constitutes the first report of a radical-anion chain substitution reaction with allylic rearrangement.

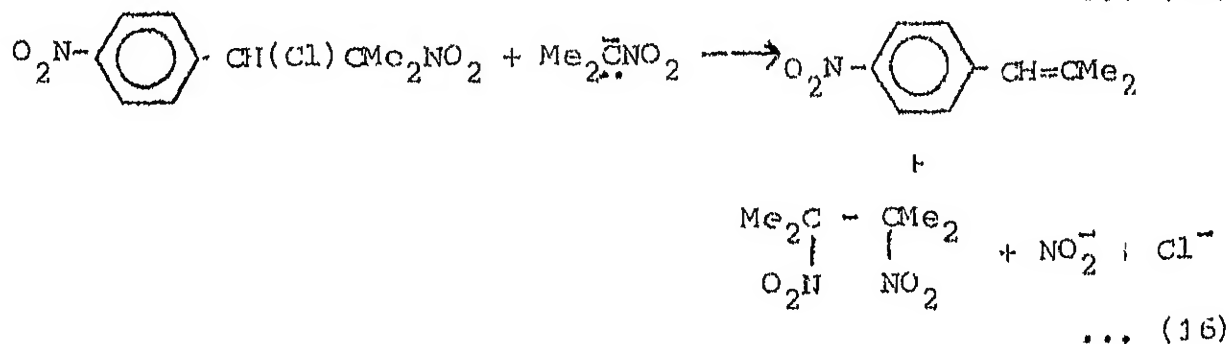
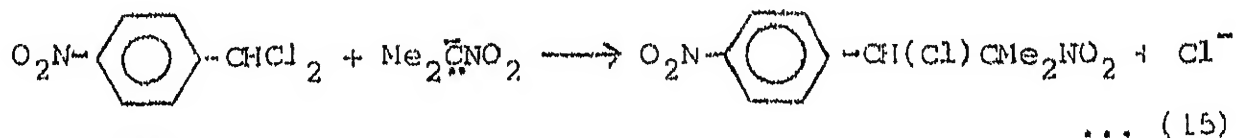


Where $\text{Ar} = \text{p-O}_2\text{NC}_6\text{H}_4$ and $\text{X}^{\cdot -} = \text{Me}_2\ddot{\text{C}}\text{NO}_2$ or $\text{Me}\ddot{\text{C}}(\text{COORt})_2$.

This corresponds to an $\text{S}_{\text{RN}}1'$ mechanism and has been named so by Norris and Barker.²⁴⁴

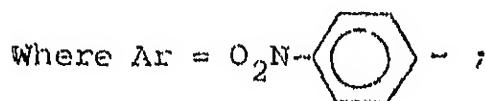
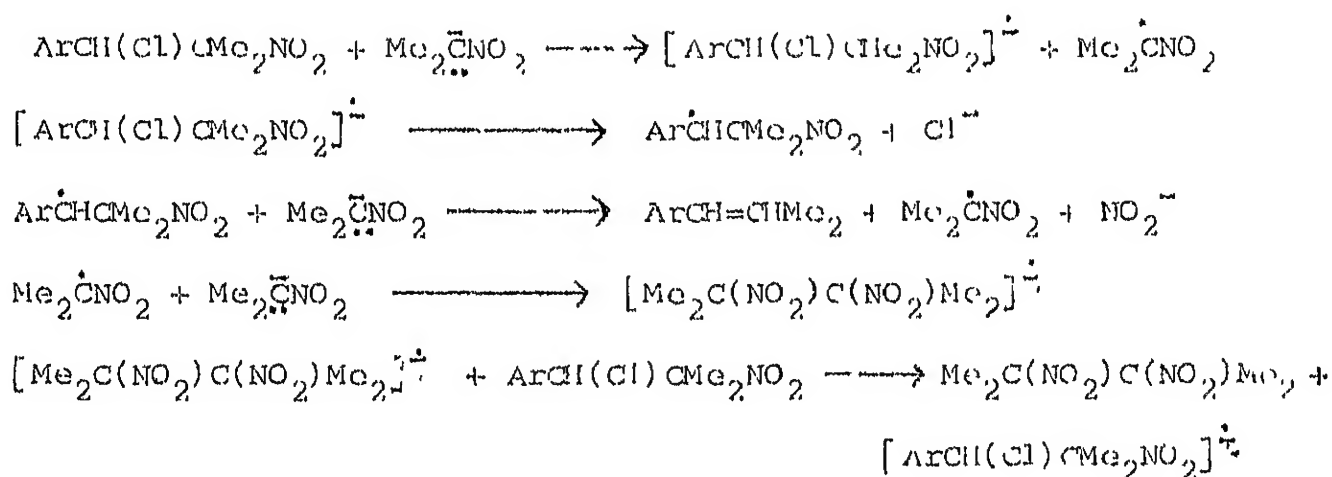
Electron transfer pathways have been proposed for the reactions of geminally and vicinally substituted leaving groups. The reaction of p-nitrobenzylidene dichloride with 2-nitropropanate anion is postulated²⁴⁵⁻²⁴⁷ to be occurring in two steps as shown in Scheme I.26.

SCHEME I.26



Both the steps shown above are inhibited by p-dinitrobenzene and accelerated by light. Eqn. 15 represents a $S_{RN}1$ reaction⁸⁰ and for the reaction represented by Eqn. 16, Freeman and Norris²⁴⁵ have proposed the mechanism outlined in Scheme I.27.

SCHEME I.27



Freeman and Norris²⁴⁵ have named the above pathway as $E_{RC}1$ (Elimination, radical chain unimolecular). Other reactions proposed to occur via $E_{RC}1$ mechanism are conversion of vicinal dinitroalkanes into alkenes by treatment with thiophenoxide or sulfide anions and conversion of vicinal dinitro or β -nitrosulfones with tributyl tinhydride²⁴⁸ as shown in Scheme I.28.

Base catalysed elimination reactions of 4-nitrobenzyl halides and dimethyl-4-nitrobenzylsulfonium ion,^{253, 254} have been reported to occur via electron transfer pathways.

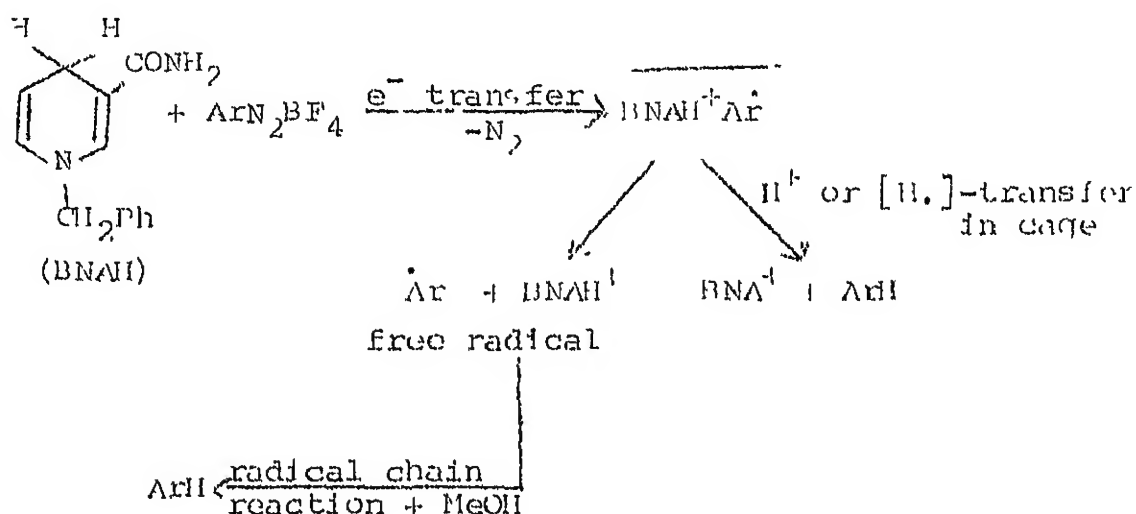
Recently, Ashby et.al.¹²⁴ have reported ESR signals, giving evidence for a single electron transfer mechanism to be operative in aldol condensation reactions. The possibility that a radical chain mechanism may be operating in the reactions was investigated by carrying out reactions under normal laboratory light, in dark, and in the presence of 5 mole per cent of p-dinitrobenzene.

Single electron transfer pathway has also been proposed for benzilic ester and/or acid rearrangement by Scroettas et.al.¹²⁶. Benzil and 9,10-phenanthrene dione are transformed into the benzilic acid-type esters by the action of Li-tert butoxide in THF-benzene medium. The semidione of the diketone has been shown by ESR to be an intermediate.

Radical mechanism¹²⁷ was favoured for Nelsonheimer rearrangement by finding out that in the rearrangement of $\text{MePhN(O)-CH}_2\text{Ph}$, MePhNO was detected by ESR and also that this rearrangement could be carried out photochemically as well as thermally.

Radical species have been observed¹²⁸ by means of ESR in the Cannizzaro reactions conducted on various substituted benzaldehydes with NaOH in THF/HMPA (9:1). The radical species have been identified as the aldehyde radical-anions corresponding to the particular aldehyde studies.

Direct evidence for one electron transfer mechanism in the reduction of arenediazonium salt has been obtained by Shin-ichi Yasui et.al.¹⁴⁸ The proposed mechanism is outlined below:

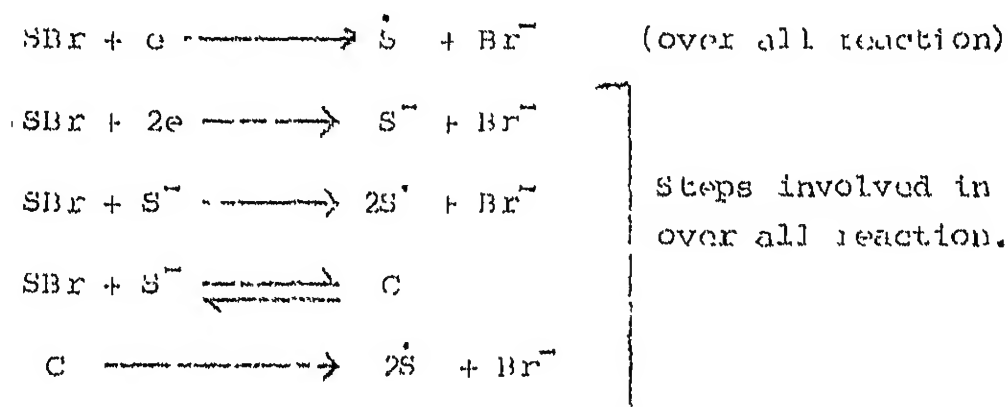


Concerning the reduction of alkyl halides by lithium aluminum hydride, Ashby et.al.¹⁴¹ have given evidence that AlH_3 produced in situ is the one electron transfer agent as evidenced by the cyclized products in the reduction of 6-iodo-1-heptene, by the trapping of the radical and by stereochemical studies of 2-halo-octanes.

The reaction of Grignard reagents with thio-benzophenone have been shown with the help of ESR to follow radical mechanism.^{142, 143} Photolytically generated tert. butoxyl radicals react with vinyl and propenyl ethers by hydrogen abstraction and addition to the double bond; Korth and Sustmann¹⁵² have done a detailed ESR study of the above reaction.

Electron transfer mediated reduction of N-chlorosuccinimide by succinimide anion has been studied by Barry et al.¹⁴⁴ The succinimide anion $S^{\cdot -}$, generated by 2-electron reduction of SBr, is an intermediate in this reaction and the same has been demonstrated by trapping experiments in which the anion is captured by an alkylating agent such as methyl tosylate, to give N-alkyl succinimides. The steps involved in this process are shown in Scheme I.31.

SCHEME I.31



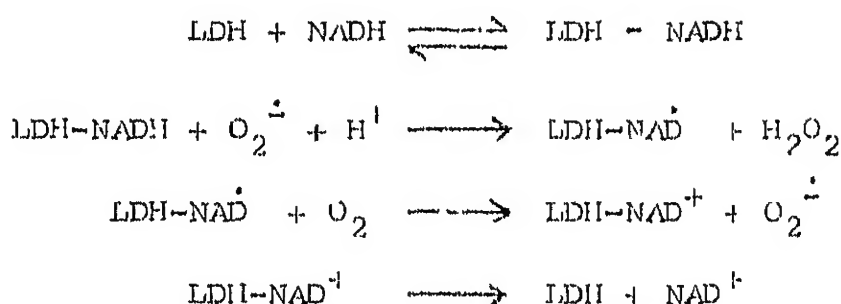
Padwa¹⁴⁵ has reported free radical cyclizations of several bromo allyl and diallyl substituted sulfonamides. According to him, the regiochemical course of these cyclizations depends on the nature of the substituent groups attached to the β -bond.

Bromination of a few alkyl aromatics have been carried out by Singh et al.¹⁴⁶ using NBS in polar solvents - DMF and acetic acid. The observations of these workers indicate that both free radical chain and ionic mechanisms are operating simultaneously

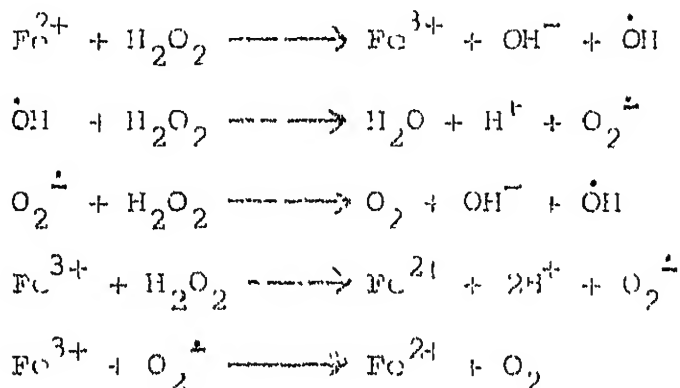
and in competition with each other. Occurrence of competitive side-chain vs nuclear bromination reactions on toluene using HgO-Br₂ reagent has also been demonstrated by Singh et al.¹⁴⁷

Photosynthetic reactions are also known to occur mostly by one electron transfer processes.²⁶⁹ A study of the superoxide-NADH system has revealed that the oxidation of NADH in the presence of an enzyme-lactate dehydrogenase, is a chain reaction for which the mechanism outlined in Scheme I.32 has been suggested.^{267, 268}

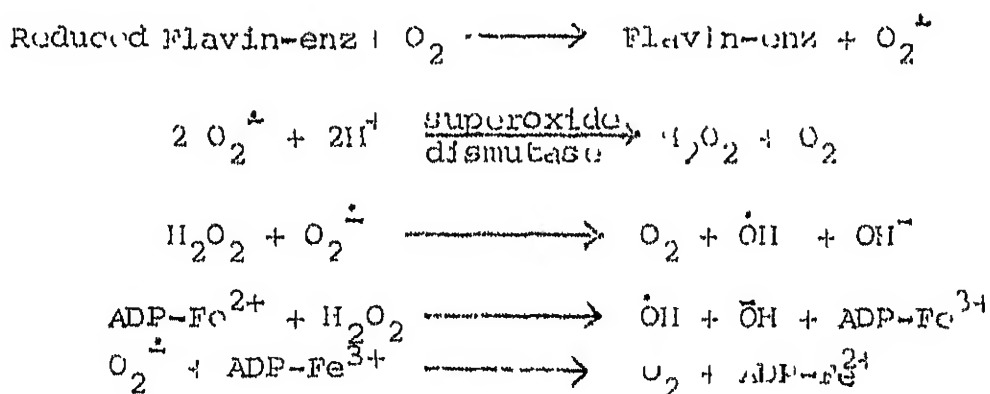
SCHEME I.32



Transition metal complexes occurring in the cell have been found to catalyze the decomposition of peroxides.²⁵⁵⁻²⁵⁸ The process is thought to be similar²⁵⁹ to the well known Haber-Weiss cycle²⁶⁰ in which iron catalyzes the decomposition of H₂O₂ by an electron transfer pathway, leading to the formation of hydroxyl radicals as shown in Scheme I.33.

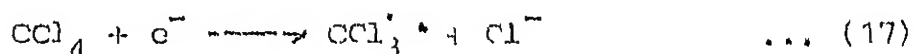
SCHEME I.33

Several oxidative enzymes, such as xanthine oxidase, also produce hydroxyl radicals^{261, 262} by a sequence of reactions involving superoxide ion and hydrogen peroxide in the presence of chelated iron as shown in Scheme I.34.

SCHEME I.34

Hydroxyl radicals so formed are potent oxidants and may initiate chain reactions in the surrounding lipid membranes leading to the destruction of tissues and consequently to aging.²⁶³

Toxicity in small doses of chloro compounds, such as chloroform and CCl_4 , has been suggested to be due to the peroxidation of endoplasmic reticulum lipids in a reaction initiated by an electron transfer from electron donors such as donor sites in enzymes.^{264, 265} (Eqn. 17).



Ethanol, even in small doses, may induce a radical chain reaction in the liver mitochondrial lipids possibly leading to fat accumulation and necrosis typical of alcoholism. In this case too, the initial radical production may result by an electron transfer from an intermediate in the normal electron transport chain.²⁶⁶

Thus, electron transfer processes leading to the formation of free radicals have been reported to occur in several important biological systems too. The foregoing discussion highlights the significance of electron transfer processes in chemical and biological systems.

The above discussion reveals that though much ground has been covered in the area of electron transfer processes, a lot still remains unexplored, offering opportunities for mechanistic investigations. Keeping this in view, we have studied a few reactions, described in the following chapters, which were known to proceed by uncertain pathways and have now been found to involve electron transfer processes.

1.3 REFERENCES

1. M. Berthelot, Justus Liebig's., Ann. Chem., 143, 97 (1867).
2. M. Bechmann and T. Paul, Ann. Chem., 266, 1 (1891).
- 3.a. J. Kenner, Chem. and Ind., 469 (1933).
- b. J. Kenner, Nature, 156, 369 (1945).
4. J.G. Smith and D.J. Mitchell, J. Am. Chem. Soc., 99, 5045 (1977).
- 5.a. S. Sorensen, G. Levin and M. Szwarc, J. Am. Chem. Soc., 97, 2341 (1975).
- b. Z. Csuros, P. Caluwe and M. Szwarc, J. Am. Chem. Soc., 95, 6171 (1973).
6. J.A. Campbell, R.W. Koch, J.V. Hay, M.A. Ogliaruso and J.L. Wolfe, J. Org. Chem., 39, 146 (1974).
7. M. Julia and B. Malassine, Tetrahedron Lett., 2495 (1972).
8. D.Y. Meyers, R.R. Grabbe and P.D. Gardner, Tetrahedron Lett., 533 (1973).
9. V. Kalyanaraman and M.V. George, J. Org. Chem., 38, 507 (1973).
10. B. Kaempf, S. Kaynal, A. Collet, F. Delme, L. Bollaen and J.M. Lehn, Angew. Chem., Int. Ed., Eng., 13, 611 (1974).
11. C.G. Scrottas, J. Chem. Soc. (Perkin II), 745 (1974).
12. J.A. Marshall and M.E. Dewollyn, J. Org. Chem., 42, 1311, (1977).
13. J.A. Marshall, L.J. Karas and R.D. Royce, Jr., J. Org. Chem., 44, 2994 (1979).
14. E.C. Ashby and T.L. Wiesemann, J. Am. Chem. Soc., 100, 189 (1978).
15. E.C. Ashby and T.L. Wiesemann, J.S. Bowers Jr., and J. Lacmule, Tetrahedron Lett., 21 (1976).

16. E.C. Ashby, J. Jaccamo and H.M. Neumann, *Acc. Chem. Res.*, 7, 272 (1974).
17. D.J. Schaeffer, R. Litman and H.E. Zieger, *Chem. Comm.*, 483 (1971).
18. G.A. Russell, E.G. Janzen and E.T. Storm, *J. Am. Chem. Soc.*, 84, 4155 (1962).
19. G.A. Russell, E.G. Janzen and E.T. Storm, *J. Am. Chem. Soc.*, 86, 1807 (1964).
- 20.a. W.A. Nugent, F. Bertini and J.K. Kochl, *J. Am. Chem. Soc.*, 96, 4945 (1974).
- b. J.K. Kochl, *Acc. Chem. Res.*, 7, 351 (1974).
21. H.O. House and M.J. Umen, *J. Am. Chem. Soc.*, 94, 5495 (1972).
22. P.R. Singh, S.R. Tayal and A. Migam, *J. Organometal. Chem.*, 42, C9 (1972).
23. S. Limatibul and J.W. Watson, *J. Org. Chem.*, 37, 4491 (1972).
24. T.M. McKlinney and D.H. Geske, *J. Am. Chem. Soc.*, 87, 3013 (1965).
25. S.K. Taylor, S.G. Bennet, K.J. Heinz and L.K. Lashley, *J. Org. Chem.*, 46, 2194 (1981).
26. S. Olivella, M. Ballesster and J. Castaner, *Tetrahedron Lett.*, 587 (1974).
27. A.H. Reddoch, *J. Chem. Phys.*, 43, 225 (1965).
28. G.A. Russel and R.L. Blankespoor, *Tetrahedron Lett.*, 4573 (1971).
29. D.J. Cowley, M.H. Millen and W.A. Waters, *J. Chem. Soc.(B)*, 2393 (1971).

- 30.a. I.R. Bellobono, P. Govoni and P. Zavattarello, J. Chem. Soc. (Perkin II), 981 (1974).
- b. I.R. Bellobono, F. Zavattarello and P.L. Beltrame, J. Chem. Soc. (Perkin II), 983 (1974).
- 31.a. P.R. Singh and B. Jayaraman, Ind. J. Chem., 12, 1306 (1974).
- b. P.R. Singh and R. Kumar, Tetrahedron Lett., 613 (1972).
- c. P.R. Singh and R. Kumar, Aust. J. Chem., 25, 2133 (1972).
32. W.T. Dixon and P.O.C. Norman, J. Chem. Soc., 4857 (1964).
33. A.H. Lewin, M.C. Peterson and R.J. Michl, J. Org. Chem., 39, 2747 (1974).
34. A.H. Lewin, A.H. Dinwoodie and T. Cohen, Tetrahedron, 22, 1527 (1966).
35. I.H. Elson and J.K. Kochl, J. Am. Chem. Soc., 95, 5060 (1973).
36. T.A. Cooper, J. Am. Chem. Soc., 95, 4158 (1973).
37. H.O. House and E.F. Kinloch, J. Org. Chem., 39, 1173 (1974).
38. B.C. Dickerman, D.J. DeSouza and N. Jacobson, J. Org. Chem., 34, 710 (1969) and references cited therein.
39. T.T. Tsou and J.K. Kochi, J. Am. Chem. Soc., 100, 1634 (1978).
40. A.L.J. Beckwith and R.O.C. Norman, J. Chem. Soc.(B), 403 (1969).
41. R.M. Klosson, F.F. Gadallah and K.F. Schulz, J. Org. Chem., 36, 1526 (1971).
42. K. Maruyama, S. Suzue and J. Osugi, Bull. Chem. Soc. Jpn., 44, 1161 (1971).
43. Y. Ogata and M. Yamashita, J. Org. Chem., 38, 3423 (1973).
44. C.A. Auden and J.R.L. Smith, J. Chem. Soc.(B), 1741, 1745 (1971).

45. H.D. Roth and A.A. Lamola, *J. Am. Chem. Soc.*, 96, 6270 (1974).
46. R.S. Davidson and S.P. Orton, *Chem. Comm.*, 209 (1974).
47. N.C. Yang and J. Libman, *J. Am. Chem. Soc.*, 95, 5783 (1973).
48. C.L. Jenkins and J.K. Kochl, *J. Am. Chem. Soc.*, 94, 843, 856 (1974).
49. A. Onopchenko and J.C.D. Schulz, *J. Org. Chem.*, 38, 3729 (1973).
50. C.L. Greenstock and T. Dunlop, *J. Am. Chem. Soc.*, 95, 6917 (1973).
51. N.H. Anderson, M. McMillan and R.O.C. Norman, *J. Chem. Soc.(B)*, 1075 (1970).
52. K. Okamoto, K. Komatsu, O. Murai and O. Sakaguchi, *Tetrahedron Lett.*, 4989 (1974).
53. H. Hart, J.S. Fleming and J.L. Dye, *J. Am. Chem. Soc.*, 86, 2079 (1964).
54. K.A. Bilevitch, N.N. Bubnov and O. Yuokhlobystin, *Tetrahedron Lett.*, 3465 (1968).
- 55.a. E.I. Heiba, R.M. Dessau and W.J. Kohel Jr., *J. Am. Soc.*, 91, 6830 (1969).
- b. R.M. Dessau, S. Shih and E.I. Heiba, *J. Am. Chem. Soc.*, 92, 412 (1970).
56. J.K. Kochl, R.T. Tang and T. Bernath, *J. Am. Chem. Soc.*, 95, 7114 (1973).
57. M. Hajek, P. Silhavy and J. Malek, *Collection Czechoslov. Chem. Commun.*, 44, 2393 (1979).
58. Ch. Elschenbroich, F. Gerson and J.A. Reiss, *J. Am. Chem. Soc.*, 99, 60 (1977).

59. B. DeGroof, G. Levin and M. Szwarc, *J. Am. Chem. Soc.*, 99, 474 (1977).
60. T.J. Katz and C. Talcott, *J. Am. Chem. Soc.*, 88, 4732 (1966).
61. S.F. Nelson and J.P. Gillespie, *J. Org. Chem.*, 38, 3592 (1973).
62. S.V. Ley and L.A. Paquette, *J. Am. Chem. Soc.*, 96, 6670 (1974).
63. D.H. Peckovich, A.H. Redloch and D.F. Williams, *Chem. Commun.*, 1195 (1972).
64. H.O. House and R.R. Kinloch, *J. Org. Chem.*, 39, 747 (1974).
65. S.F. Nelson, *J. Org. Chem.*, 38, 2693 (1973).
66. B.J. McClelland, *Chem. Rev.*, 64, 301 (1964).
67. N. Kushiiki and H. Yoshida, *J. Am. Chem. Soc.*, 98, 268 (1976).
68. J.F. Garst and F.E. Barton II, *J. Am. Chem. Soc.*, 96, 523 (1974).
69. K.B. Wiberg and G.A. Epling, *Tetrahedron Lett.*, 1119 (1974).
70. M. Schlosser, *Angew. Chem. Int. Ed. Eng.*, 3, 287 (1964).
71. E.de. Roer, *Adv in Organometal. Chem.*, 2, 115 (1964).
72. M. Szwarc, "Carbanions, Living Polymers and Electron Transfer Processes", Interscience, New York, 1968.
73. M. Anbar, *Adv. Phys. Org. Chem.*, 7, 117 (1969).
74. L.M. Dorfman, *Acc. Chem. Res.*, 3, 224 (1970).
- 75.a. N.L. Holy and J.D. Horcum, *Angew. Chem. Int. Ed. Eng.*, 10, 115 (1971).
- b. N.L. Holy, *Chem. Rev.*, 74, 243 (1974).
76. L.L. Miller, *J. Chem. Edu.*, 48, 168 (1971).
77. M. Szwarc, *Acc. Chem. Res.*, 5, 169 (1972).

78. J.F. Garst, *Acc. Chem. Res.*, 4, 400 (1971).
79. J.F. Garst in "Free Radicals", J.K. Kochi (Ed.), Wiley Interscience, New York, 1973, Chapter 9.
80. N. Kornblum, *Angew. Chem. Int. Ed. Engl.*, 14, 734 (1975).
81. J.F. Bunnet, *Acc. Chem. Res.*, 11, 415 (1978).
82. J.F. Wolfe and D.P. Carber, *Org. Prepar. Proced. Int.*, 10, 225 (1978).
83. D.R. Arnold and A.O. Maroulis, *J. Am. Chem. Soc.*, 99, 7355 (1977).
84. C.L. Kwan and J.K. Kochi, *J. Am. Chem. Soc.*, 98, 4903 (1976).
85. A.L. Balch, *J. Am. Chem. Soc.*, 98, 285 (1976).
86. E.T. Kaiser and L. Kevan, "Radical Ions" Interscience, New York, 1968.
87. C.N.R. Rao, V. Kalyanaraman and M.V. George, *Appl. Spect. Rev.*, 3, 153 (1970).
88. E. Hayon and M. Simic, *J. Am. Chem. Soc.*, 95, 1029 (1973).
89. B.W. Hangerter, R.P. Beatty, J.K. Foubba and S.S. Wretford, *J. Org. Chem.*, 42, 3247 (1977).
90. W. Schlenk and P. Weickel, *Chem. Ber.*, 44, 1182 (1911).
91. W. Schlenk and A. Jhal, *Chem. Ber.*, 46, 1840 (1913).
92. W.E. Bachman, *J. Am. Chem. Soc.*, 55, 1179 (1933).
93. C.B. Wooster, *J. Am. Chem. Soc.*, 59, 377 (1937).
94. S. Sugden, *Trans. Faraday Soc.*, 30, 18 (1934).
95. E. Muller and W. Janke, *Z. Electrochem.*, 45, 380 (1939).
96. R.M. Doescher and G.W. Wheland, *J. Am. Chem. Soc.*, 56, 2011 (1934).

97. E. Muller and W. Wieseman, *Z. Angew. Chem.*, 51, 657 (1938).
98. H. Gilman and J.C. Baillic, *J. Am. Chem. Soc.*, 65, 267 (1943).
99. I.D. Bauld, *J. Am. Chem. Soc.*, 84, 4345 (1962).
- 100.a. A.W. Burgstanler and L.R. Worden, *J. Am. Chem. Soc.*, 86, 96 (1964).
- b. J.W. Huffman, D.L. Alboran and G.W. Rotha, *J. Org. Chem.*, 27, 3381 (1962).
- 101.a. A.K. Hoffmann, W.G. Hodgson, D.L. Parole and W.H. Jura, *J. Am. Chem. Soc.*, 86, 631 (1964).
- b. A.K. Hoffmann, A.M. Feldman and T. Colbium, *J. Am. Chem. Soc.*, 86, 646 (1964).
102. D. Devaprabhakara and P.D. Gardner, *J. Am. Chem. Soc.*, 85, 648 (1963).
103. J.M. Brown, *Chem. and Ind. (London)*, 42, 1689 (1964).
104. G. Stork and J. Tsuji, *J. Am. Chem. Soc.*, 83, 2783 (1961).
- 105.a. A.J. Birch, *Quart. Rev. (London)*, 4, 69 (1950).
- b. A.J. Birch and H. Smith, *Quart. Rev. (London)*, 12, 17 (1958).
106. "Modern Synthetic Reactions", H.O. House, W.A. Benjamin Inc., New York, Amsterdam, pp.50-71.
107. R.A. Benkeser and E.H. Kaiser, *J. Org. Chem.*, 29, 955 (1964).
108. R.A. Benkeser and C.A. Tincher, *J. Org. Chem.*, 33, 2727 (1968).
109. H. Kwart and R.A. Conley, *J. Org. Chem.*, 38, 2011 (1973).
- 110.a. M.C.R. Symons, *Quart. Rev. (London)*, 13, 99 (1959).
- b. H. Gold, W.L. Jolly and K.S. Pitzer, *J. Am. Chem. Soc.*, 84, 2264 (1962).

111. E.D. Popp and H.P. Schultz, *Chem. Rev.*, 62, 19 (1962).
112. M. Narisada and F. Matsunabe, *J. Org. Chem.*, 38, 3887 (1973).
- 113.a. J.G. Smith, I. Ho and G.W.F. Simpson, *J. Org. Chem.*, 40, 495 (1975).
- b. J.G. Smith and D.J. Mitchell, *J. Am. Chem. Soc.*, 99, 5045 (1977).
114. B.P. Giri, *Ind. J. Chem.*, 19B, 72 (1980).
115. Ujjaja Prasad, (Mrs) Geeta Singh and K.N. Mehrotra, *Ind. J. Chem.*, 19B, 653 (1980).
116. Y. Minoura and S. Tsuboi, *J. Org. Chem.*, 37, 2064 (1972).
117. G. Levin, S. Claesson and H. Szwarc, *J. Am. Chem. Soc.*, 94, 8672 (1972).
118. J.F. Garst, R.D. Roberts, J.A. Pacifici, *J. Am. Chem. Soc.*, 99, 3528 (1977) and references cited therein.
- 119.a. P.R. Sanera, W. Scinski, M.M. Hanson, T.O. Hara and B. Byrne, *J. Org. Chem.*, 38, 642 (1973).
- b. I. Shlota, K. Okhaja and T. Hanatusa, *Chem. Lett.*, 1153 (1974).
- c. P.W. Rabidean, D.L. Huser and S.J. Nyikos, *Tetrahedron Lett.*, 1401 (1980).
- 120.a. G.H. Markgraf, W.M. Hensby, and D.L. Snook, *J. Org. Chem.*, 39, 3168 (1974) and references cited therein.
- b. G.H. Small, A.V. Minnolla and S.W. Hall, *J. Org. Chem.*, 40, 3151 (1975).
121. L. Shanne and M.W. Haemel, *Tetrahedron Lett.*, 4245 (1979).
122. M. Vora and P. Holy, *J. Org. Chem.*, 40, 3144 (1975).
123. F. Maiolo, L. Testaferri, M. Tiecco and M. Tlingoli, *J. Org. Chem.*, 46, 3070 (1981).

124. B.C. Ashby, J.N. Argyropoulos, G. Richard Meyer and A.B. Goel, *J. Am. Chem. Soc.*, 104, 6788 (1982).
125. J.F. Markgraf, B.L. Basla and P.W. Wege, *J. Org. Chem.*, 37, 2361 (1972).
126. C.G. Screttas, M.M. Screttas, and C.T. Cazianis, *Tetrahedron Lett.*, 24, 3287 (1983).
127. U. Schöllkopf, M. Jatsch and H. Schäfer, *Tetrahedron Lett.*, 2515-20 (1964).
128. B.C. Ashby, David T. Coleman III and M. Pilar Gamasa, *Tetrahedron Lett.*, 851 (1983).
129. N.D. Scott, J.F. Walker and V.L. Hansley, *J. Am. Chem. Soc.*, 58, 2442 (1936).
- 130.a. J.F. Garst, P.W. Ayers and R.C. Lamb, *J. Am. Chem. Soc.*, 88, 4260 (1966).
 b. J.F. Garst, J.T. Barbas and F.W. Barton II, *J. Am. Chem. Soc.*, 90, 7159 (1968).
 c. J.F. Garst and J.T. Barbas, *Tetrahedron Lett.*, 3125 (1969).
- 131.a. G.D. Sargent, J.N. Cron and S. Bank, *J. Am. Chem. Soc.*, 88, 5363 (1966).
 b. G.D. Sargent and M.W. Browne, *J. Am. Chem. Soc.*, 89, 2788 (1967).
 c. G.D. Sargent, *J. Am. Chem. Soc.*, 90, 7161 (1968).
 d. P.D. Walsh and R. Dabestani, *J. Org. Chem.*, 46, 1222 (1981).
132. D.B. Ledlie, R.L. Thorne and G. Weiss, *J. Org. Chem.*, 36, 2186 (1971).
133. G.D. Sargent and G.A. Lux, *J. Am. Chem. Soc.*, 90, 7160, (1968).

- 134.a. J.F. Garst and J.W. Barbas, J. Am. Chem. Soc., 91, 3385 (1969).
- b. J.F. Garst and J.T. Barbas, J. Am. Chem. Soc., 96, 3239 (1974).
- c. H.E. Sieger, L. Angres and D. Mathison, J. Am. Chem. Soc., 98, 2580 (1976).
135. R.C. Lamb, P.W. Ayers, and M.K. Percy, J. Am. Chem. Soc., 85, 3483 (1963).
136. D. Bryce-Smith, J. Chem. Soc., 1603 (1956); Bull. Soc. Chim. Fr., 1418 (1968).
137. G.A. Russell and D.W. Hanson, J. Am. Chem. Soc., 91, 3967 (1969).
138. H. Fischer, J. Phys. Chem., 73, 3834 (1969).
139. "Organometallic Mechanisms and Catalysis", J.K. Kochl, Academic Press, New York, 1978, pp. 246-368.
- 140.a. G. Boche, D.R. Schneider and H. Wintermeyer, J. Am. Chem. Soc., 102, 5697 (1981).
- b. P.K. Freeman and L.L. Hutchinison, J. Org. Chem., 45, 3191 (1980).
141. H.C. Asby, R.M. DePiest and W.N. Pham, Tetrahedron Lett., 24, 2825 (1983).
142. M. Dagonneau and J. Vialle, Tetrahedron, 30, 3119 (1974).
143. M. Dagonneau, J. Organomet. Chem., 80, 1 (1974).
144. John E. Barry, Manuel Finkelstein, W. Michael Moore and Sidney D. Ross, J. Org. Chem., 50, 528 (1985).
145. A. Padwa, H. Nimmesgern and G.S.K. Wong, Tetrahedron Lett., 26, 957 (1985).

- 146.a. P.R. Singh and R.K. Khanna, Tetrahedron Lett., 24, 973 (1983).
b. P.R. Singh and R.K. Khanna, Tetrahedron Lett., 24, 1411 (1983).
147. P.R. Singh and N. Govindraj, unpublished results from the Ph.D. Thesis of NG, Indian Institute of Technology, Kanpur, India.
148. Shinro Yasui, Kaoru Nakamura, Atsuyoshi Ohno, Tetrahedron Lett., 24, 3331-34 (1983).
- 149.a. P.R. Singh, B. Jayaraman and R.K. Singh, Chem. and Ind., 311 (1977).
b. G. Levin, T.A. Ward and M. Szwarc, J. Am. Chem. Soc., 96, 270 (1974); 97, 258 (1975).
c. P.R. Singh, R. Kumar, Ind. J. Chem., 13, 692 (1973).
150. S. Bank and S.P. Thomas, Tetrahedron Lett., 305 (1971).
151. S. Bank and S.P. Thomas, J. Org. Chem., 42, 2858 (1977).
152. H.G. Korth and R. Sustmann, Tetrahedron Lett., 26, 2551 (1985).
- 153.a. R.G.H. Kirstetter, Chem. Ber., 112, 2804 (1979).
b. W. Tochtermann and R.G.H. Kirstetter, Chem. Ber., 111, 1228 (1978).
154. J.W. Stinnett, M.M. Vora and D.D. Holy, Tetrahedron Lett., 3821 (1974).
155. S. Bank, T.A. Lois and M.C. Prislowski, J. Am. Chem. Soc., 91, 5407 (1969).
- 156.a. F.A. Cotton and G. Wilkinson, "Advanced Inorganic Chemistry", 2nd Ed., Interscience, New York, 1966, pp.55.
b. S. Bank and D.A. Noyd, Tetrahedron Lett., 1413 (1969).

- 157.a. J.F. Walker and H.D. Scott, J. Am. Chem. Soc., 60, 951 (1938).
b. A. Misono, I. Ogata and K. Shimada, Chem. Abstr., 69, 5897p (1968); Nippon Kagaku Zasshi, 88, 1116 (1967).
- 158.a. D.R. Wayenberg and L.H. Toporcer, J. Org. Chem., 30, 943 (1965).
b. L. Birkofer and K. Ramadan, Chem. Ber., 104, 138 (1971).
159. S.J. Snaper, W.D. Closson, J.M.F. Van Dijk, O. Piepers and H.M. Buck, J. Am. Chem. Soc., 99, 5118 (1977).
160. G.B. Bachman and R.S. Barker, J. Am. Chem. Soc., 69, 1535 (1947).
161. G.D. Gutsche, I.Y.C. Tao and J. Kozma, J. Org. Chem., 32, 1782 (1967).
- 162.a. E.E. Van Tamelan, R.B. Fechter and S.W. Schneller, J. Am. Chem. Soc., 91, 7196 (1969).
b. E.E. Van Tamelan, J.H. Gladysz and J.S. Miller, J. Am. Chem. Soc., 95, 1347 (1973).
c. J. Chatt, G.A. Heath and R.L. Richards, Chem. Comm., 1010 (1972).
163. S. Band and D.A. Boyd, J. Am. Chem. Soc., 95, 8203 (1973).
164. J.F. Bunnett, K. Creary and J.D. Sundberg, J. Org. Chem., 41, 1707 (1976).
165. H.K. Singh, Ph.D. Thesis, Indian Institute of Technology, Kanpur, India, August 1979.
166. J.J. Lubinkowski, J.W. Knapczyk, J.L. Calderon, L.R. Petit and W.E. McEwen, J. Org. Chem., 40, 3010 (1975).
167. A.G. Evans and D.B. George, J. Chem. Soc., 4653 (1961).
168. G.A. Russell and E.G. Janzen, J. Am. Chem. Soc., 84, 4153 (1962).

169. F.G. Bordwell and A.H. Clemens, *J. Org. Chem.*, 46, 1035 (1981).
170. G.R. Stevenson, M. Colon, J.G. Concepcion and A. McBlock, *J. Am. Chem. Soc.*, 96, 2283 (1974).
171. C.G. Screttas, *Chem. Comm.*, 868 (1972).
172. R.E. Van Tamelen, J.I. Brauman and L.E. Ellis, *J. Am. Chem. Soc.*, 87, 4964 (1965); 93, 6141 (1971).
- 173.a. H.O. House, *Acc. Chem. Res.*, 9, 59 (1976) and references cited therein.
- b. D.J. Hannah, A.J. Smith, I. Teoh and R.W. Weavers, *Aust. J. Chem.*, 34, 181 (1981).
174. R.A. Olofson and C.M. Dougherty, *J. Am. Chem. Soc.*, 95, 582 (1973).
175. X. Creary, *J. Am. Chem. Soc.*, 99, 7632 (1977).
176. R.C. Lamb, P.W. Ayers, M.K. Toney and J.F. Garst, *J. Am. Chem. Soc.*, 88, 4261 (1966).
177. G. Blomberg, R.H. Salinger and H.J. Mosner, *J. Org. Chem.*, 34, 2385 (1969).
178. J.F. Favargue and R. Rouget, *C.R. Hebdom. Seances Acad. Sci. Ser. C*, 267, 1355 (1968).
179. T. Holm and T. Crossland, *Acta Chem. Scand.*, 25, 59 (1971).
180. E.C. Ashby, *Pure and Appl. Chem.*, 52, 545 (1980).
181. E.C. Ashby, J.R. Bowers and R.M. Depriest, *Tetrahedron Lett.*, 21, 3541 (1980).
182. E.C. Ashby and J.R. Bowers, *J. Am. Chem. Soc.*, 103, 2242 (1981).
183. H. Takajo, M. Nojima and S. Kusabayashi, *J. Am. Chem. Soc.*, 104, 1636 (1982).

184. E.C. Ashby, A.B. Goel and R.N. Depriest, *J. Am. Chem. Soc.*, 102, 7780 (1982).
185. E.C. Ashby, A.B. Goel, R.N. Depriest and V.L. Prasad, *J. Am. Chem. Soc.*, 103, 973 (1981).
- 186.a. Sung-Kee Chung and Fu-Fan Chung, *Tetrahedron Lett.*, 2473 (1979).
- b. Sung-Kee Chung, *J. Org. Chem.*, 45, 3513 (1980).
187. E.C. Ashby, R.N. Depriest and A.B. Goel, *Tetrahedron Lett.*, 22, 1763 (1981).
188. E.C. Ashby and A.B. Goel, *J. Org. Chem.*, 46, 3934 (1981).
189. P.R. Singh, J.M. Khurana and Alok Nigam, *Tetrahedron Lett.*, 22, 2901 (1981).
190. P.R. Singh, Alok Nigam and J.M. Khurana, *Tetrahedron Lett.*, 21, 4753 (1980).
- 191.a. E.C. Ashby, A.B. Goel and R.N. Depriest, *J. Org. Chem.*, 46, 2429 (1981).
- b. E.C. Ashby, A.B. Goel and J.N. Argyropoulos, *Tetrahedron Lett.*, 23, 2273 (1982).
192. G.R. Newkome and D.C. Mager, *J. Org. Chem.*, 47, 599 (1982).
193. H.B. Hass and M.L. Bender, *J. Am. Chem. Soc.*, 71, 1767, 3482 (1949).
194. N. Kornblum, P. Pink and K.V. Yorka, *J. Am. Chem. Soc.*, 83, 2779 (1961).
195. R.C. Kerber, G.W. Urry and N. Kornblum, *J. Am. Chem. Soc.*, 86, 3904 (1964).
196. R.C. Kerber, G.W. Urry and N. Kornblum, *J. Am. Chem. Soc.*, 87, 4520 (1965).

197. N. Kornblum and R.C. Kerber, J. Am. Chem. Soc., 88, 5660 (1966).
198. N. Kornblum, R. E. Michel and R.C. Kerber, J. Am. Chem. Soc., 88, 5662 (1966).
199. G.A. Russell and W.C. Danen, J. Am. Chem. Soc., 88, 5663 (1966).
200. G.A. Russell and W.C. Danen, J. Am. Chem. Soc., 90, 347 (1968).
201. N. Kornblum and F.W. Stuchal, J. Am. Chem. Soc., 92, 1804 (1970).
202. N. Kornblum and H. Cheng, unpublished work.
203. N. Kornblum, S.D. Boyd and N. Ono, J. Am. Chem. Soc., 96, 2580 (1974) and references cited therein.
204. a. N. Kornblum, T.N. Davies, G.W. Earl, N.L. Holy, R.C. Kerber, M.F. Musser and D.H. Snow, J. Am. Chem. Soc., 89, 725 (1967).
b. N. Kornblum, T.N. Davies, G.W. Earl, G.S. Greene, N.L. Holy, R.C. Kerber, J.W. Manthey, M.F. Musser and D.H. Snow, J. Am. Chem. Soc., 89, 5714 (1967).
205. N. Kornblum and F.W. Stuchal, J. Am. Chem. Soc., 92, 1804 (1970).
206. N. Kornblum, G.W. Earl, N.L. Holy et al., J. Am. Chem. Soc., 90, 6221 (1968).
207. N. Kornblum, R.T. Swiger, G.W. Earl, et al., J. Am. Chem. Soc., 92, 5513 (1970).
208. N. Kornblum, S.D. Boyd and F.W. Stuchal, J. Am. Chem. Soc., 92, 5783 (1970).
209. N. Kornblum, T.N. Davies and coworkers, J. Am. Chem. Soc., 90, 6219 (1968).

- 210.a. N. Kornblum, S.C. Carlson, J. Widmer, M.J. Fielot, B.N. Newton and R.G. Smith, *J. Org. Chem.*, 43, 1394 (1978).
- b. N. Kornblum, P. Ackermann and R.W. Swiger, *J. Org. Chem.*, 45, 5294 (1980).
211. N. Kornblum, S.D. Boyd and E.W. Stuchal, *J. Am. Chem. Soc.*, 92, 5784 (1970).
212. N. Kornblum, M.M. Kestner, S.D. Boyd and L.C. Cattran, *J. Am. Chem. Soc.*, 95, 3356 (1973).
213. N. Kornblum, S.D. Boyd, A.W. Pinnick and R.G. Smith, *J. Am. Chem. Soc.*, 93, 4316 (1971).
214. L.W. Seigle and H.B. Hass, *J. Org. Chem.*, 5, 100 (1940).
215. E.E. Van Tamelen and G. Van Zyl, *J. Am. Chem. Soc.*, 71, 835 (1949).
- 216.a. W. Russell-Bowman and G.D. Richardson, *J. Chem. Soc. (Perkin I)*, 1407 (1980).
- b. W. Russell-Bowman and G.D. Richardson, *Tetrahedron Lett.*, 1551 (1981).
- 217.a. G.A. Russell, M. Jawdosluk and M. Makosza, *J. Am. Chem. Soc.*, 101, 2355; G.A. Russell and A.R. Metcalfe, *ibid.*, 101, 2359.
- b. G.A. Russell, P.K. Norris and B.J. Panek, *J. Am. Chem. Soc.*, 93, 5839 (1971).
218. M. Barreau and M. Julia, *Tetrahedron Lett.*, 1537 (1973).
- 219.a. G.A. Russell, J. Hersberger and K. Owens, *J. Am. Chem. Soc.*, 101, 1312 (1979).
- b. G.A. Russell and J. Hersberger, *Chem. Comm.*, 216 (1980).

- 220.a. G.A. Russell and J. Hershberger, *Synthesis*, 475 (1980).
b. G.A. Russell and J. Hershberger, *J. Am. Chem. Soc.*, 102, 7603 (1980).
221. G.A. Russell and J.H. Pecoraro, *J. Am. Chem. Soc.*, 101, 3331 (1979).
222. R.K. Norris and D. Randles, *J. Org. Chem.*, 47, 1047 (1982).
223. B. Bigot, D. Roux and I. Salem, *J. Am. Chem. Soc.*, 103, 5271 (1981).
224. J.K. Kim and J.F. Bunnett, *J. Am. Chem. Soc.*, 92, 7463 (1970).
225. J.F. Bunnett, *Acc. Chem. Res.*, 11, 413 (1978).
226. N. Kornblum, S.D. Boyd and N. Ono, *J. Am. Chem. Soc.*, 96, 2580 (1974).
227. S. Hoz and J.F. Bunnett, *J. Am. Chem. Soc.*, 99, 4690 (1977).
228. R.G. Scammon and J.F. Bunnett, *J. Org. Chem.*, 42, 1449 (1977).
229. R.A. Rossi and J.F. Bunnett, *J. Am. Chem. Soc.*, 94, 683 (1972).
230. R.A. Rossi and J.F. Bunnett, *J. Org. Chem.*, 37, 3470 (1972).
231. J.F. Bunnett and B.F. Gloor, *J. Org. Chem.*, 38, 4156 (1973).
- 232.a. R.A. Rossi and J.F. Bunnett, *J. Org. Chem.*, 38, 3020 (1973).
b. J.F. Bunnett and J.E. Sundberg, *Chem. Pharm. Bull.*, 23, 2620 (1975).
233. R.A. Rossi, R.H. deRossi and A.F. Lopez, *J. Org. Chem.*, 41, 3371 (1976).
234. J.F. Bunnett and B.F. Gloor, *J. Org. Chem.*, 38, 382 (1974).
- 235.a. C. Galli and J.F. Bunnett, *J. Am. Chem. Soc.*, 101, 6137 (1979).
b. J.F. Bunnett and R.P. Traber, *J. Org. Chem.*, 43, 1367 (1978).

236. R.A. Alonso and R.A. Rossi, *J. Org. Chem.*, 47, 77 (1982).
237. Ramesh Kumar, Ph.D. Thesis, Indian Institute of Technology, Kanpur, India, August 1973.
238. C. Galli and J.F. Bunnett, *J. Am. Chem. Soc.*, 103, 7140 (1981).
239. R.R. Bard and J.F. Bunnett, *J. Org. Chem.*, 45, 1546 (1980).
240. R. Beugelmans and H. Gensburg, *Chem. Comm.*, 508 (1980).
241. R. Beugelmans, B. Boudet and L. Quintero, *Tetrahedron Lett.*, 1943 (1980).
242. J.F. Bunnett and P. Singh, *J. Org. Chem.*, 46, 5022 (1981).
243. A.R. Katritzky, G.Z. deVelle and R.C. Patel, *Tetrahedron Lett.*, 1723 (1980).
244. S.D. Barker and R.K. Norris, *Tetrahedron Lett.*, 973 (1979).
245. D.J. Freeman and R.K. Norris, *Aust. J. Chem.*, 29, 2631 (1976).
246. H. Rottendorf, S. Steinhell and J.R. Welmsurts, *Aust. J. Chem.*, 18, 1759 (1965).
247. E.W. Van Tamelen and G. van Zyl, *J. Am. Chem. Soc.*, 71, 835 (1949).
248. N. Ono, H. Miyake, R. Tamura, I. Hamamoto and A. Kaji, *Chem. Lett.*, 8, 1139 (1981).
249. W. Adam and J. Arco, *J. Org. Chem.*, 37, 507 (1972).
250. C.G. Scouton, W.F. Barton Jr., J.R. Burgess, P.R. Stony and J.F. Garst, *Chem. Comm.*, 78 (1969).
- 251.a. G.D. Sargent, C.M. Tatum and S.M. Kastner, *J. Am. Chem. Soc.*, 94, 7174 (1972).
- b. G.D. Sargent, C.M. Tatum and R.P. Scott, *J. Am. Chem. Soc.*, 96, 1602 (1974).

252. P.R. Singh and B. Jayaraman, Chem. Lett., 1333 (1976).
253. a. S.B. Hanna and P.H. Ruenle, J. Org. Chem., 40, 3882 (1975).
b. F.M. Fouad and P.G. Farrell, J. Org. Chem., 40, 3881 (1975).
254. G.L. Gloss and S.H. Goh, J. Chem. Soc. (Perkin II), 1473 (1972).
255. A.L. Tappel in "Autoxidation and Antioxidants" (W.O. Lundberg, ed), Vol. 1, p.325, Wiley (Interscience), New York, 1961.
256. E.D. Wells, Biochem. J., 113, 315 (1969).
257. J.L. Poyer and P.B. McCay, J. Biol. Chem., 246, 263 (1971).
258. A.L. Tappel in "Lipids and their Oxidation" (H.W. Schultz, E.A. Day and R.O. Sinnhuber, eds), p.122, Avi Publ., Westport, Connecticut, 1962.
259. J.M. McLord, Science, 185, 629 (1974).
260. F. Haber and J. Weiss, Proc. Roy. Soc., Ser. A, 147, 332 (1934).
261. P.B. McCay, P.M. Pfeiffer and W.H. Steele, Ann. N.Y. Acad. Sci., 203, 62 (1972).
262. K.L. Fong, P.B. McCay, J.L. Poyers, B.B. Steele and H. Misra, J. Biol. Chem., 248, 7792 (1973).
263. W.A. Pryor, Sci. Amer., 223, 70 (1970).
264. W.A. Pryor and W.H. Hendrickson, J. Am. Chem. Soc., 97, 1582 (1975).
265. W.A. Pryor and W.H. Hendrickson, J. Am. Chem. Soc., 97, 1580 (1975).
266. N.R. Diluzio, Fed. Proc. Fed. Am. Soc. Exp. Biol., 32, 1875 (1973).

- 267. H.J. Land and A.O. Swallow, Biochem. Biophys. Acta, 234, 34 (1971).
- 268. D.R. Storm and D.E. Koshland, Jr., J. Am. Chem. Soc., 94, 5805 and 5815 (1972).
- 269. Paul A. Loach and B.J. Hales in "Free radicals in Biology", (W.A. Pryor, ed.) Vol.I, p.199, Academic Press, New York, 1976.

CHAPTER II

REDUCTIVE CLEAVAGE OF DIORGANOMERCURIALS VIA SINGLE ELECTRON TRANSFER

II.1 Abstract

The reactions of a few symmetrical and unsymmetrical organomercurials $R-Hg-R$ and $R-Hg-R'$ viz., dibenzyl mercury, diphenyl mercury and pphenyl-p-tolyl mercury with varying amounts of sodium naphthalene in THF solvent were examined at $30^{\circ}C$ under nitrogen atmosphere. Instantaneous separation of metallic mercury was observed in each of these reactions. Besides, naphthalene and monomeric hydrocarbons, dimeric products $R-R$ in the reactions of $R-Hg-R$ and mixtures of biaryls in the reactions of $R-Hg-R'$ were also obtained. The recovered starting materials from incomplete reactions of $R-Hg-R'$ contained small amounts of $R-Hg-R$ and $R'-Hg-R'$ also. Though the reactions of diorgano-mercurials with equimolar quantities of sodium naphthalene were

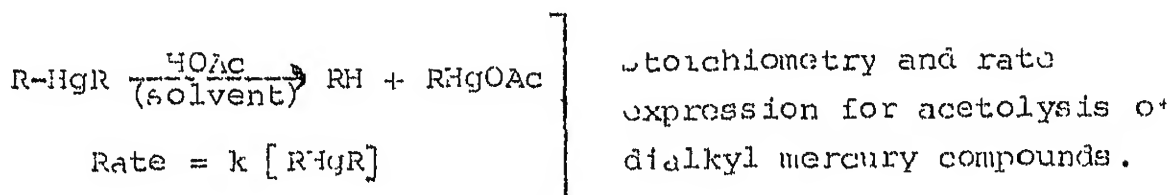
largely incomplete in 30 min., more of the starting material was consumed on increasing the reaction time. The reactions were complete in 30 min. with twice the molar quantity of sodium naphthalene. On the basis of these and other observations, an electron transfer free radical mechanism involving the occurrence of a $\pi^* \rightarrow \pi^*$ electron transfer from the naphthalene radical anion to the diorganomercurials has been proposed to account for the observed facts.

The reactions of the same three above mentioned organomercurials with LiAlH_4 in THF solvent at 30°C under dry nitrogen, commenced with the evolution of hydrogen gas and simultaneous separation of metallic mercury. Each diorganomercury R-Hg-R or R-Hg-R' , completely reacted with an equimolar amount of LiAlH_4 in 30 min. yielding organic compounds similar to those obtained in the reactions with $\text{Na}^+\text{Napn}^{\cdot-}$. Formation of R-Hg-H in these reactions is considered unlikely. A new electron transfer mechanism has been proposed which satisfactorily accounts for the initial generation of radicals and anionic intermediates, besides rationalising all the observations recorded for these reactions.

II.2 Introduction

Whitmore's¹ treatise deals with the history and important developments in the chemistry of organomercury compounds. Initial studies of Frankland² on the preparation of organomercurials have been followed by an ever-increasing interest in the properties and reactions of these materials. One of the earliest investigated reactions of these compounds was the protic acid cleavage of the carbon-mercury bond.

A systematic study of the acid-cleavage reaction of diorganomercurials in acetic acid solvent was reported in 1955 by Winstein and Praylor.³

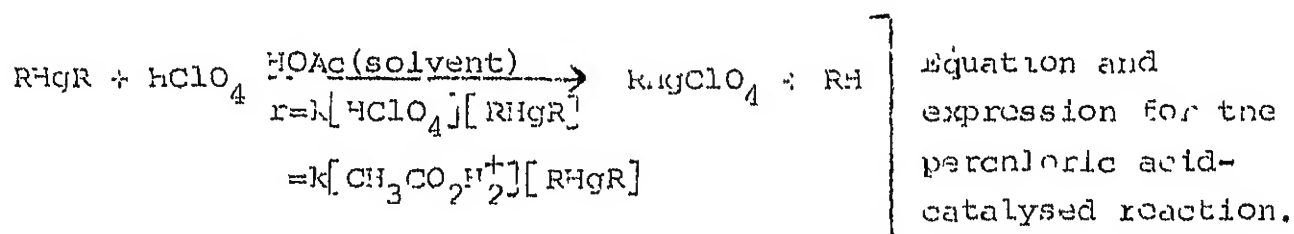


Pseudo first-order rate constants⁴ were found for the compounds diphenyl mercury, di-sec-butyl mercury, di-n-butyl mercury and dineophyl mercury. The reaction rate found to be in the order: sec-butyl > n-butyl is opposite of that found for the cleavage of unsymmetrical dialkyl mercury compound. This illustrates the dependence of these reaction rates also on the second substituent attached to mercury.

The effect of added sodium acetate was investigated in the cleavage of dineophyl mercury. As no change in the rate was

observed, it was taken as an evidence that neither nucleophilic attack of acetate ion on mercury nor reaction with the conjugate acid of acetic acid is important. Added perchloric acid gave greatly, the enhanced rates, and under these conditions, obeyed second-order kinetics.

The mechanism proposed for the acetolysis reaction was classified as S_E1 involving molecular acetic acid. The S_N2 mechanism using protonated acetic acid was suggested for the bimolecular reaction which occurred with added perchloric acid, but it was pointed out that possibilities such as ion pair involvement could not be ruled out.

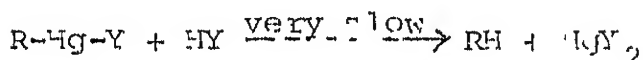


During the course of this work^{5,6} it was seen that alkyl mercuric cation was undergoing decomposition to yield metallic mercury and acid. This reaction was attributed to oxidation of solvent by alkyl mercuric cation reflecting a situation akin to a simple solvolysis proceeding through a carbocation.

Several organometallic and organoelemental compounds have been prepared from organomercury compounds by reaction with halides of other metals and non-metals and also by the action of free

metals, resulting in organometallic compounds of the latter (i.e. other metals actually used).⁷ Treatment of diethyl mercury with sulfuric acid giving pure ethane was suggested by Schorlemmer⁸, in 1864. Shortly thereafter, Otto⁹ demonstrated analogous acid cleavage of diaryl mercurials and also examined the reactions of several other reagents with the aryl carbon mercury bond.

Generally, cleavage of dialkyl compounds occurs much more readily than the corresponding reaction of the alkyl mercuric salt, since, electronegative elements attached to mercury would tend to lower the electron density at the carbon site.

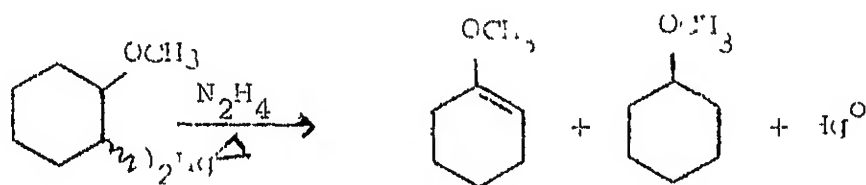


Kharasch¹⁰, in 1925, studied the acid cleavage of unsymmetrical organomercurials. Relative ease of cleavage of mixed alkyl and aryl organomercurials by HCl (100-1) was determined in these experiments. Kharasch^{10c} and Flenner, consequently, gave several important conclusions

- (a) the aryl carbon-mercury bond is broken much more readily than alkyl carbon-mercury bond;
- (b) the positions of the tolyl, phenyl and chlorophenyl groups parallel their respective rates of nitration;

- (c) any substituent replacing a hydrogen of the methyl group causes a decrease in relative rate;
- (d) chain branching and increasing chain length lead to a decreased relative rate of cleavage.

Formation of hydrocarbon and olefinic products by reduction of diorganomercurials has been established by Wright.¹¹



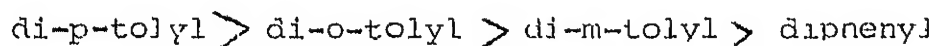
However, it is well known that dialkyl mercury compounds are stable to water and alcohol and since carbanions would be expected to react immediately with these solvents, it is clear that ionization cannot be occurring.

The order of decreasing ease of cleavage of groups in unsymmetrical organomercurials by hydrogen chloride according to Kharasch and coworkers¹⁰

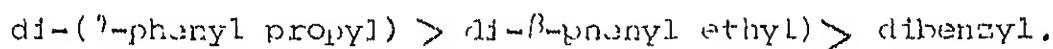
Aryl	Alkyl ^a
p-anisyl	methyl
o-anisyl	ethyl
α -naphthyl	n-propyl ^b
p-tolyl	n-butyl
m-tolyl	isoamyl
phenyl	benzyl ^c
p-chlorophenyl	cyclohexyl ^d
o-chlorophenyl	
m-chlorophenyl	

- All the alkyl substituents were found to be cleaved less readily than the aryl substituents.
- The isopropyl group fell below n-propyl in this series, but its relationship to n-butyl was not definitely established.
- Both t-butyl and β -phenyl ethyl fell below benzyl, but were not further interrelated.
- The effect of increasing chain length is shown by the relative position of n-C₁₆H₃₃, which was found to be comparable to cyclohexyl.

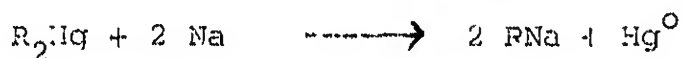
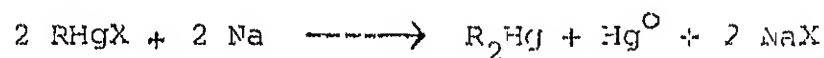
A simple second-order rate law has been found significant by Nerdel and Makower¹² who examined the scission of a series of dialkyl and diaryl mercurials by means of HCl in aqueous THF and dioxane solvents. They determined the sequences.



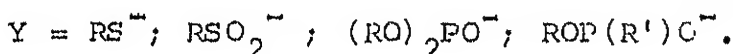
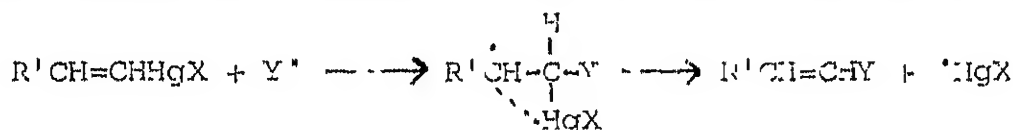
and



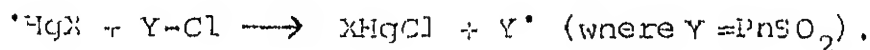
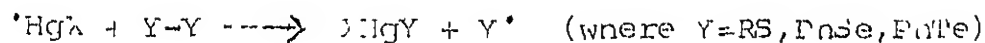
Organomercurials react with electropositive metals by an oxidation-reduction process. The reduction usually proceeds fast to give initially the diorganomercury compound and metallic mercury; and thereafter, more slowly to give the metal-alkyl and more free mercury. The electropositive metals which have been employed are sodium^{12,13}, copper¹⁴⁻¹⁶, zinc¹⁷ and magnesium¹⁸ besides cadmium, copper and silver¹⁹.



Vinyl mercurials are also known²⁰ to undergo free radical chain substitution with RSSR , PhSeSePh , PhTeTePh or PhSO_2Cl . An addition elimination process similar to that shown below has

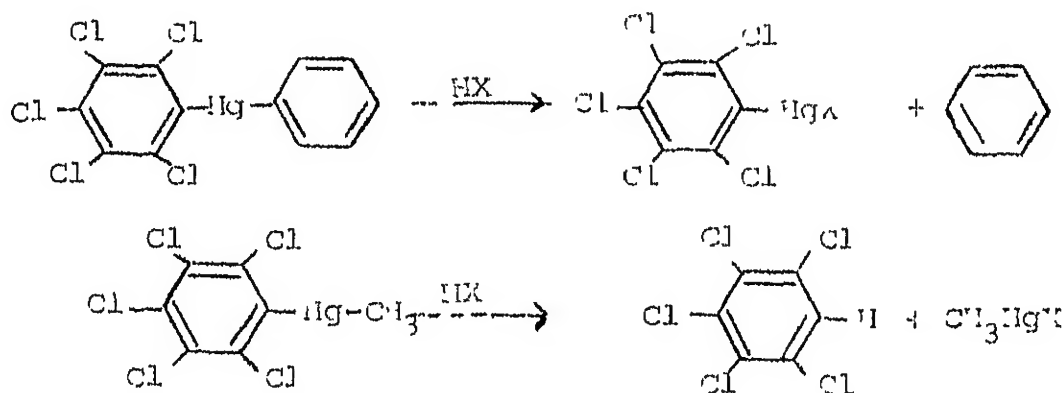


been proposed for these substitution reactions. The propagation steps postulated for these reactions are as follows:

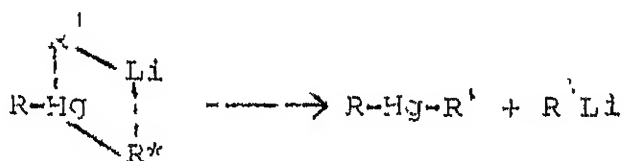


All these reactions are known to be stimulated by light and inhibited by radical scavengers.

The direction of cleavage of unsymmetrical mercurials had received little attention since the work of Kharasch. Recently, Dessy²⁰ has reported that the compounds shown below cleave in the direction anticipated for an electrophilic reaction.



The plausible path of reaction of a diorganomercurial with organolithium reagent till recently was supposed to involve a four-center exchange as shown, with racemization of alkali organometallic through ionization and dissociation.



In view of the facts that sodium naphthalene is an excellent source of electrons²¹⁻²⁴ and lithium aluminium hydride can serve as a single electron as well as hydrogen atom donor^{25, 26}, we decided to examine the details of the mechanistic roles of these two reagents in the reductive cleavage of organomercurials.

II.3 Results and Discussion:

Reduction of diorganomercurials has been affected by a variety of reagents such as sodium metal¹³, hydrogen chloride¹⁰ and hydrazine¹¹; but the mechanistic details of these reactions are obscure. Though, naphthalene radical anion is known to reduce arene diazonium cations²⁷ and certain benzylic halides²⁸ via a $\pi^* \rightarrow \pi^*$ electron transfer pathways, its reaction with diorganomercurials has not been reported in literature. Occurrence of a new electron transfer mechanism involving radical intermediates in the uncatalyzed lithium aluminium hydride reduction of 1,2-chlorostilbene²⁵ and certain benzylic halides²⁸ has been demonstrated in our laboratory.

A wide variety of reaction pathways²⁹ are available to organomercurials. Some of these have been observed and documented, others suggested but unproven, while still more are potential mechanisms which may require special forcing conditions to come into play. In view of these facts, we have examined the reactions of a few diorganomercurials with sodium naphthalene as well as lithium aluminium hydride to elucidate the relevant mechanisms.

The reactions of dibenzyl mercury 1a, diphenyl mercury 1b and phenyl-p-tolyl mercury 1c with varying amounts of sodium naphthalene in THF solvent at 30°C under nitrogen atmosphere gave the products listed in Table II.1 along with an unestimated amount of metallic mercury which was also obtained in all these reactions.

Table II.1: Reactions^a of diorganomercurials 1 with sodium naphthalene

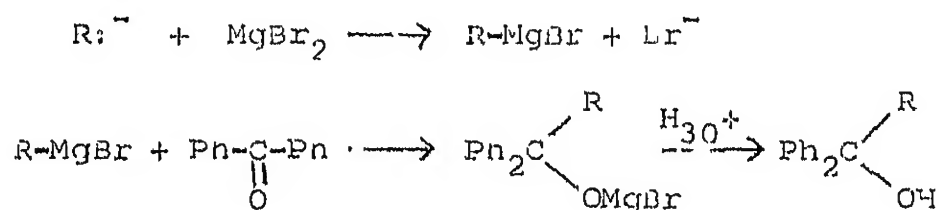
Run	Diorgano mercury R-Hg-R' 1	Molar ratio C ₁₀ H ₈ :1	Reac- tion time (min)	% yield of products ^b						Starting material 1
				R-H	R-R	R'-H	P'-R'	naphtha- lene ^c		
1	<u>1a</u>	1.00	30	16	5	-	-	85	76	
2	<u>1a</u>	1.00	360	21	7	-	-	90	70	
3	<u>1a</u>	2.00	30	65	31	-	-	90	-	
4 ^d	<u>1a</u>	1.00	30	12	5	-	-	92	82	
5 ^d	<u>1a</u>	2.00	30	58	32	-	-	90	8	
6 ^e	<u>1a</u>	2.00	30	71	27	-	-	87	-	
7 ^f	<u>1a</u>	1.00	240	15	5	-	-	89	74	
8	<u>1b</u>	1.00	30	31	6	-	-	88	61	
9	<u>1b</u>	1.00	360	34	7	-	-	93	57	
10	<u>1b</u>	2.00	30	80	18	-	-	92	-	
11 ^d	<u>1b</u>	1.00	30	24	5	-	-	90	68	
12 ^e	<u>1b</u>	1.00	240	22	6	-	-	90	63	
13	<u>1c</u>	1.00	30	15	4	10	9 ^(g)	85	60 ⁽ⁿ⁾	
14	<u>1c</u>	2.00	30	41	9	26	20 ^(g)	91	-	

Table II.1 (contd.)

- a) 5×10^{-3} mol of R-Hg-R' were reacted with $\text{Na}^+\text{C}_{10}\text{H}_8^{*}$ in THF at 30°C , under N_2 atmosphere; 1a: $\text{R}=\text{R}'=\text{C}_6\text{H}_5\text{CH}_2-$, 1b: $\text{R}=\text{R}'=\text{C}_6\text{H}_5-$ and 1c: $\text{R}=\text{C}_6\text{H}_5$, $\text{R}'=\text{p-H}_3\text{C-C}_6\text{H}_4-$
- b) Percentage based on diorganomercury, unless otherwise stated. An unestimated amount of metallic mercury was also obtained in these reactions. Mercury was separated from other products during work up by filtration through celite.
- c) Percentage based on sodium naphthalene.
- d) In the presence of 5×10^{-3} mol naphthalene added from outside. Yield of naphthalene based on the total amount of naphthalene, obtainable from initially used $\text{Na}^+\text{C}_{10}\text{H}_8^{*}$ as well as C_{10}H_8 added from outside.
- e) In the presence of cumene (0.1 mol).
- f) In the presence of MgBr_2 (0.01 mol). On subsequent reaction with benzophenone, benzyl diphenyl carbinol (5% yield) in run 7 and triphenyl carbinol in run 12 were also obtained.
- g) Yield of R'-R' i.e., p,p'-bitolyl as indicated in run 13 appears to actually consist of a mixture of isomeric monomethyl biphenyls (ca. 6%) and a mixture of isomeric bitolyls (ca. 3%) and that in run 14, a mixture of isomeric monomethyl biphenyls (ca. 13%) and a mixture of bitolyls (ca. 7%).
- h) Yield of the starting material & recovered as indicated in run 13 appears to actually consist of phenyl p-tolyl mercury (ca. 51%), diphenyl mercury (ca. 4%) and p-p'-ditolyl mercury (ca. 5%).

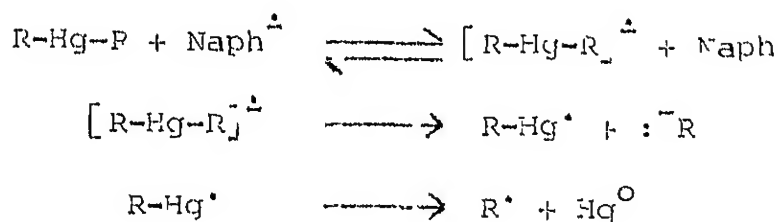
The reactions with equimolar amounts of sodium naphthalene in 10 min (runs 1, 8 and 13), were largely incomplete; but on increasing the reaction time, more of the diorganomercurial reacted in each case (as seen in runs 2 and 9). The reactions of the same three diorganomercury compounds were complete in 30 min with twice the molar quantities of sodium naphthalene (runs 3, 10 and 14).

Detection of benzyldiphenylcarbinol in the reaction of 1a (run 7) and triphenylcarbinol in the reaction of 1b (run 12) as products indicates that benzyl carbanion and phenyl carbanion, respectively exist as intermediates in these reactions.



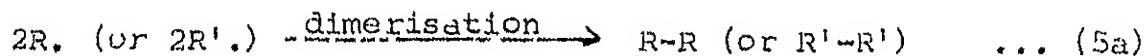
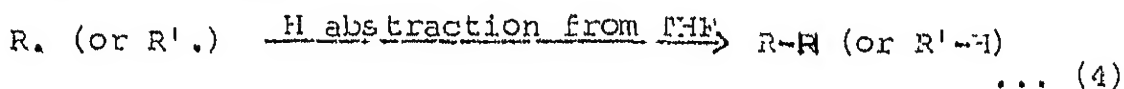
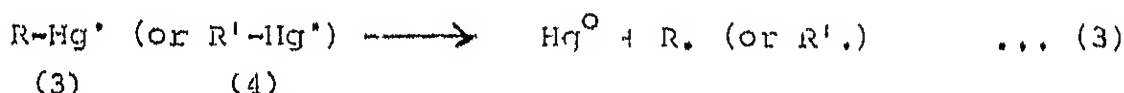
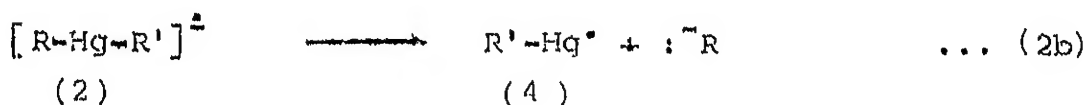
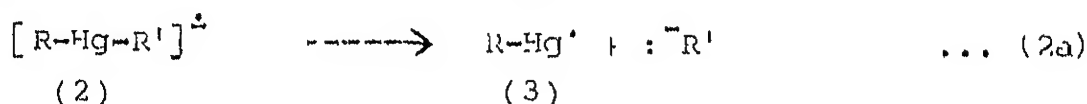
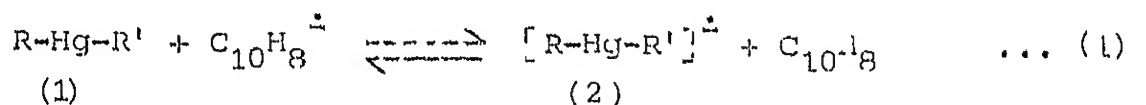
The formation of dimeric products i.e. biaryls in all these reactions, particularly, isomeric mixtures monomethylbiphenyls and ditolyls in runs 13 and 14 also suggests the existence of free radical intermediates. That the free radical intermediates are actually involved in the reaction is supported by the observation made in run 6 wherein the presence of cumene - a hydrogen atom donor in the reaction medium results in the formation of toluene in higher yield at the expense of bibenzyl.

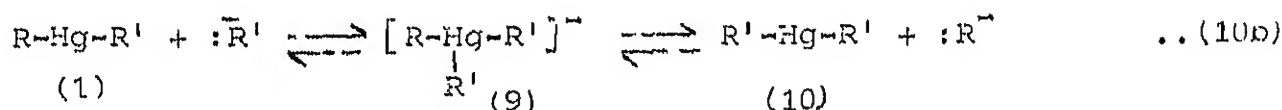
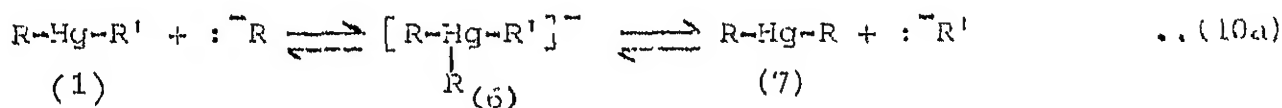
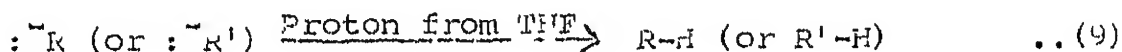
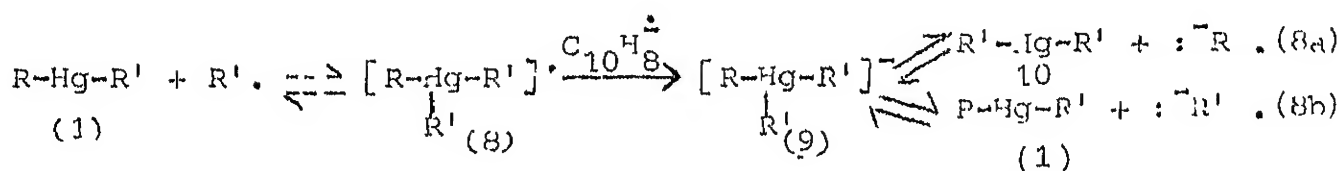
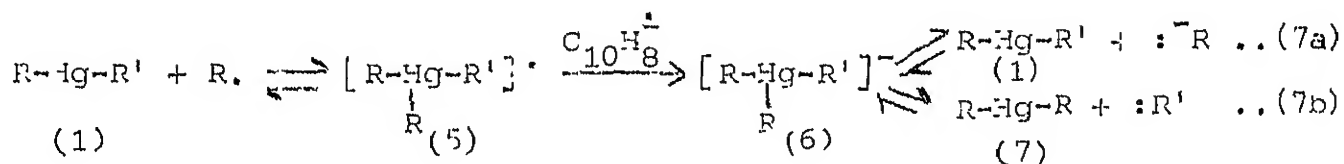
Generation of both aryl anion and aryl radical intermediates almost simultaneously is indeed expected in these reactions in view of the presence of a strong electron donor - sodium naphthalene (Na^+Naph^{2-}).



The formation of metallic mercury along with other products together with our additional observations recorded in Table II.1 and elsewhere²⁹ adequately support the occurrence of an electron transfer mechanism outlined in Scheme II.1 which we suggest for these reactions.

SCHEME II.1





The reaction is initiated by the transfer of an electron from the n^* MO of naphthalene radical-anion to the lowest unoccupied molecular orbital (LUMO) of 1. The reversibility of step 1 is evident from the retardation of the reactions of 1a and 1b in the presence of added naphthalene (equilibrium shifts toward the left) as seen in the runs 5 and 11 respectively. The radical anion 2 formed in step 1 fragments³¹ to yield the highly unstable organo-mercury radical 3 or 4 besides a carbanion as shown in steps 2a and 2b, the bond cleavage taking place in accordance with the

differential in the electronegativities of mercury and carbon atoms across that bond. The decomposition of radicals (3) and (4) to yield metallic mercury and carbon radicals as shown in step 3 is known³² to be rapid at our reaction temperature. Besides reacting as shown in steps 4, 5a and 5b, the radicals R. and R'. may add to (1) giving adduct (5) or (6)^{32,33} which on acceptance of an electron from naphthalene radical anion regenerate (1) (steps 7a and 8b) and also give R-Hg-R, (7) or R'-Hg-R', (10) as shown in steps 7b and 8a, respectively. Diorganomercurials (7) and (10) are indeed formed in runs 13 and 14. As cumene donates a hydrogen atom to benzyl radical with greater ease than T-HF does, the observed increase in the yield of toluene at the expense of bibenzyl in run 6, establishes the existence of free radical intermediates. The C-H bond strength being greater than the Hg-I bond strength, the hydrogen atom abstraction by R-Hg· or R'-Hg· radical from cumene to yield R-Hg-H or R'-Hg-H is highly unlikely.

Formation of R-H and R'-I through radicals outlined in step 4 may occur to a greater extent through carbanions produced in steps 2a, 2b, 7a, 7b, 8a, 8b or otherwise as shown in step 9. Carbanions :⁻R and :⁻R' existence of which as intermediates is proved by the trapping experiments in runs 7 and 12 are also capable of reacting with (1) in a slow, reversible manner producing diorganomercurials (7) and (10) actually found among the products in runs 13 and 14 as shown in steps 10a and 10b.

In addition to the modes shown in scheme II.1, carbanions may also be produced by the reduction of corresponding radicals with sodium naphthalene.



This is in agreement with the observed increase in the yields of monomeric hydrocarbons (vide step 9) in the reactions of diorganomercurials carried out with twice the molar quantities of sodium naphthalene (runs 3, 10 and 14).

The presence of an excess of sodium naphthalene aids the completion of the reaction by forcing the equilibrium of step 1 towards right hand side.

The reactions of the same three diorganomercurials (1a),(1b) and (1c) with varying amounts of lithium aluminum hydride (LAH) in THF medium at 30°C under dry nitrogen atmosphere gave the products listed in Table II.2 along with an unestimated amount of metallic mercury which was also obtained in all these reactions.

Table II.2: Reactions^a of diorganomercurials **1** with LiAlH_4

Run	Diorgano mercury R-Hg-R' 1.0,005 mol.	LiAlH ₄ mol.	React- ion time (min.)	% Yield of products ^b					Unreacted starting material	C ₂ (ml)
				R-H	R-R	R'-H	R'R'			
1	1a	0.005	30	64	32	-	-	-	52	
2	1a	0.0025	30	54	26	-	-	19	47	
3	1a	0.00125	30	42	12	-	-	32	30	
4	1a	0.00125	300	45	14	-	-	27	35	
5 ^d	1a	0.00125	30	48	8	-	-	44	38	
6	1b	0.005	30	81	15 ^e	-	-	-	55	
7	1b	0.0025	30	56	10	-	-	31	50	
8	1b	0.00125	30	45	8	-	-	43	30	
9	1b	0.00125	300	48	9	-	-	36	35	
10 ^f	1b	0.005	30	46	9	-	-	40	60	
11	1c	0.005	30	39	5	36	10 ^g	-	60	
12	1c	0.0025	30	24	3	16	7 ^g	48 ^h	40	
13	1c	0.00125	30	13	2	11	3 ^g	62 ^h	10	

a) Reactions conducted in THF (60 ml) at 30°C under dry nitrogen,
1a: $\text{R}=\text{R}'=\text{C}_6\text{H}_5\text{CH}_2-$; **1b**: $\text{R}=\text{R}'=\text{C}_6\text{H}_5-$ and **1c**: $\text{R}=\text{C}_6\text{H}_5-$, $\text{R}'=\text{p-H}_3\text{C}-\text{C}_6\text{H}_4-$

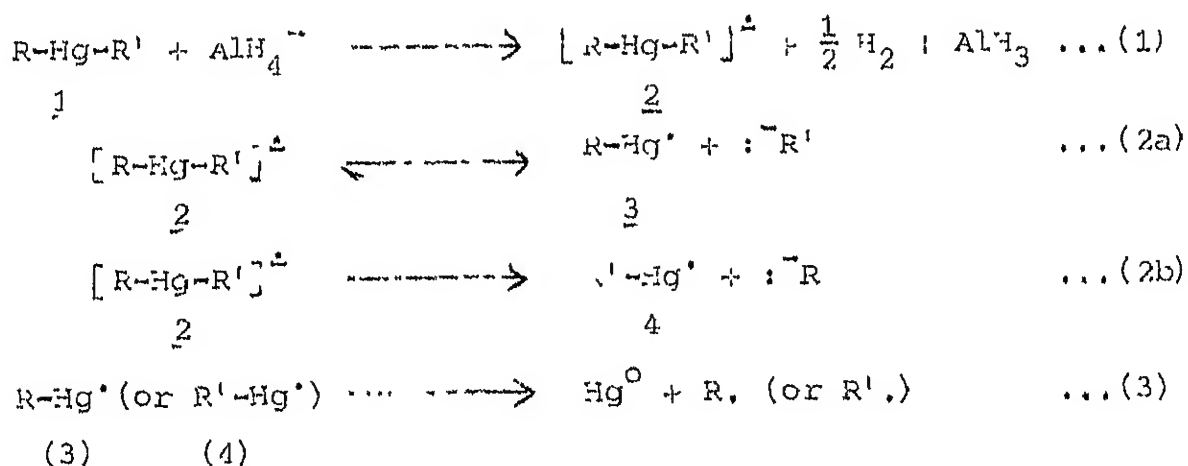
Table II.2(contd.)

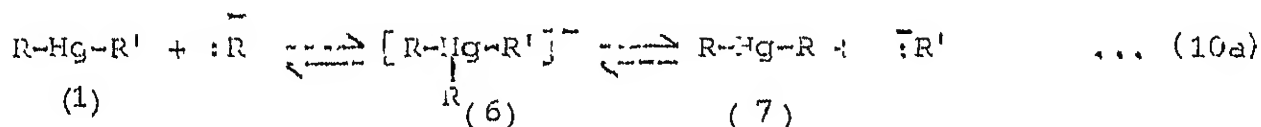
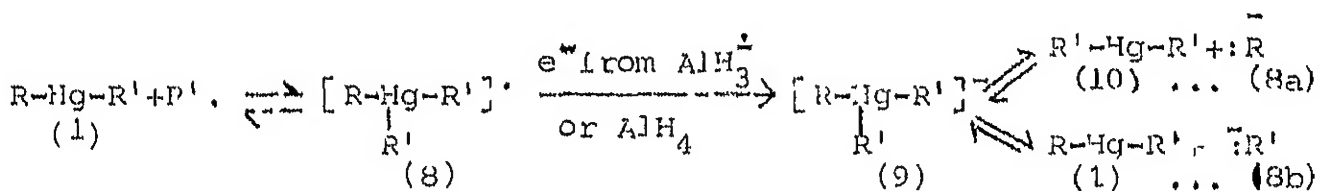
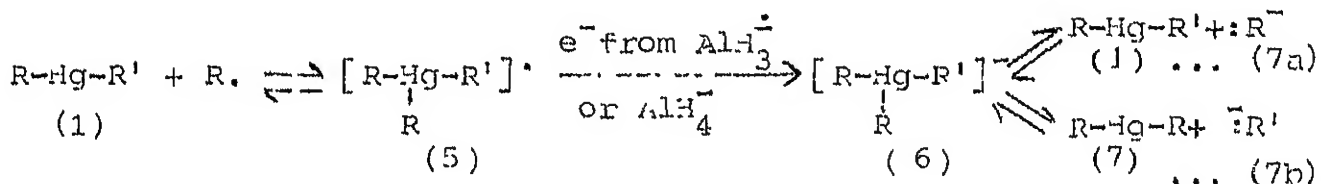
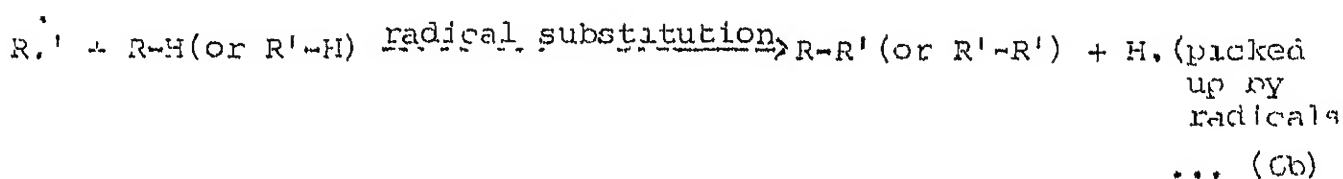
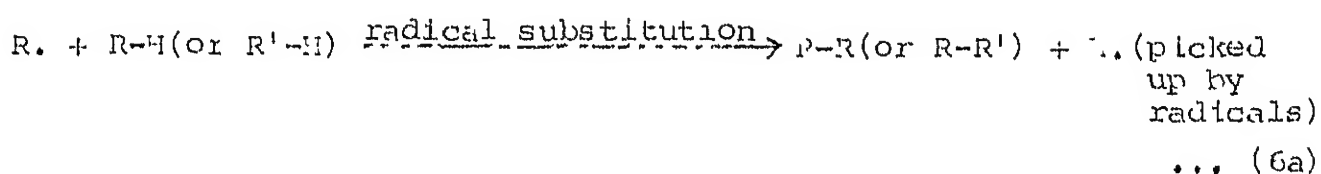
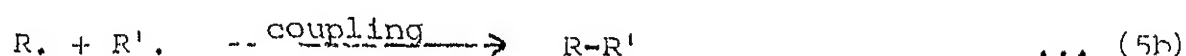
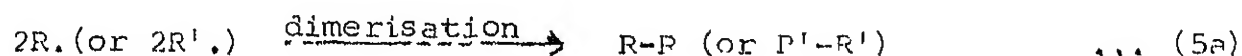
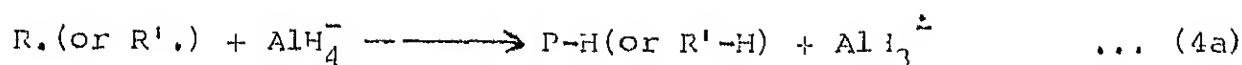
Table II.2(contd.)

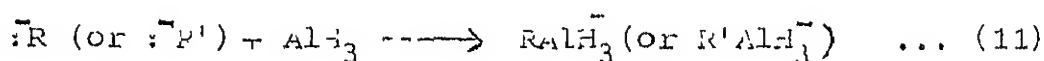
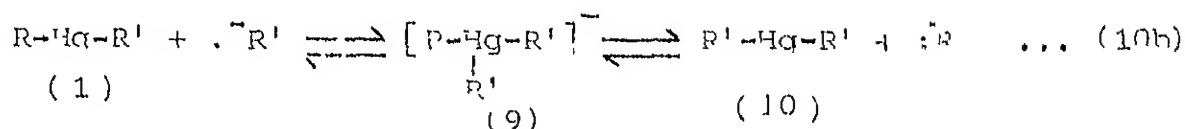
- b) Percentage yields based on $R-Hg-R'$. An unestimated amount of metallic mercury was also obtained as a product in all the reactions.
- c) Vol. of H_2 was determined at atmospheric pressure by comparison with control experiment in the absence of I using same batch of reactants and solvent under identical conditions and then converted to NTP.
- d) In the presence of cumene (0.1 mol).
- e) Yield remained essentially unaltered on estimation before and after work up of the reaction mixture.
- f) In the presence of naphthalene (0.005 mol). Naphthalene was recovered back unchanged after the reaction.
- g) Yield mentioned under $R'-R'$ i.e. p,p'-bitolyl appears actually to consist of isomeric monomethyl biphenyls (ca. 7%) and isomeric bitolyls (ca. 3%) in run 11, isomeric monomethyl biphenyls (ca. 4%) and isomeric bitolyls (ca. 4%) in run 12, and isomeric monomethyl biphenyls (ca. 2%) and isomeric ditolyls (ca. 1%) in run 13.
- h) Yields of the starting material actually consists of phenyl p-tolyl mercury (40%), diphenyl mercury (3%) and di-p-tolyl mercury (5%) in run 12, and phenyl p-tolyl mercury (52%), diphenyl mercury (6%) and di-p-tolyl mercury (4%) in run 13.

Reactions of (1) (0.005 mol) with LAH (0.00125 mol) were accompanied by the evolution of hydrogen gas and separation of metallic mercury were largely incomplete in 30 min; but somewhat more reaction took place on increasing the reaction time. With equimolar quantities of the two reactants, all the starting diorganomercurial was converted into the products (runs 1, 6 and 11). The nature and the distribution of the organic products was found to be similar to those obtained in the reaction of (1) with sodium naphthalene described in the earlier pages of this section. The effects of added cumene (run 5) and naphthalene (run 10) from outside in these reactions was also found to be similar to the effects seen in the reactions of (1) with sodium naphthalene. In view of the known ability of AlH_4^- to donate an electron to organomercurials³⁰ as well as the facts mentioned above, we propose a new electron transfer mechanism for these reactions. The essential features of this mechanism are outlined in Scheme II.2.

SCHEME II.2







This mechanism is closely similar to that described in Scheme II.1 in so far as the intermediacy of both radicals R.(or R.') and carbanions $\cdot\bar{\text{R}}$ (or $\cdot\bar{\text{R}}'$) formed by means of steps 1 to 3 is invoked.

A special feature of this mechanism, however, is the abstraction of a hydrogen atom from AlH_4^- by the radical R.(or R.') as shown in step 4a. Consequently, $\text{AlH}_3 \cdot$ is formed which effectively competes with AlH_4^- in donating an electron in step 1 and steps 7a, 7b, 8a and 8b. Coordination of the carbanion $\cdot\bar{\text{R}}$ (or $\cdot\bar{\text{R}}'$) produced in the reaction with AlH_3 also formed side by side, leads to the formation of $\text{RAlH}_3 \cdot$ (or $\text{R}'\text{AlH}_3 \cdot$) as shown in step 11. The facts that more than 50% and 25% of the reactant(1) is consumed when the molar quantities of LAH are one half and one fourth respectively, indicate towards the possibility of $\text{RAlH}_3 \cdot$ and $\text{R}'\text{AlH}_3 \cdot$ also acting as electron donors.

II.4 Experimental:

All melting points were determined on a MEL-TEMP melting point apparatus and are uncorrected. IR spectra were recorded on Perkin-Elmer model-580 spectrophotometer. The GLC analysis were carried out on a Chromatography and Instruments Company Model ACI-F1 instrument using 10% SE-30 on Crom-P (85-100M) column of 2m length. Column chromatography was done using activated silica-gel (Acme's 100-200M). Silica-gel (asc-India) was used for TLC analysis. Products were identified by comparison of their IR spectra with those of the authentic samples, by TLC, GLC, mixed melting point technique and by C & H analysis. Literature melting points are cited from 'Handbook of Chemistry and Physics', 50th edition, R.C. Weast (Ed.), published by Chemical Rubber Co., Cleveland, Ohio, unless otherwise specified.

Starting Materials:

Tetrahydrofuran (THF) was purified by keeping it over potassium hydroxide pellets overnight, refluxing over sodium wire for 5-6 h. and then distilling over sodium twice, refluxing the same for 3-4 h. with lithium aluminium hydride (LAH) followed by distillation over LAH. The distilled THF was stored in contact with freshly pressed sodium wire.

Dibenzyl mercury, diphenyl mercury and phenyl-p-tolyl-mercury were prepared by the known methods. Naphthalene (reagent grade) was used after recrystallization from ethanol. LAH (Riedel and SRL) 'high purity' was used. Cumene (Koch-light) was used after distillation. Authentic diphenyl (BDH) and bibenzyl, were used after recrystallization, benzene and toluene were used after distillation.

Preparation of sodium naphthalene:

A perfectly dry 3 necked 100 ml RB flask was mounted over a magnetic stirring base, fitted with a condenser, a gas passing adaptor, and a stopper. Naphthalene (0.64 g; 5×10^{-3} mol or 1.28 g; 0.01 mol) dissolved in dry THF (30 ml) was placed in the flask. The contents of the flask were maintained at 30°C (room temperature). Pure, dry nitrogen gas was bubbled through the solution with continuous stirring. Sodium metal (0.17g; 0.0075g-atom or 0.35g; ca 0.015g atom) cut into small pieces was added to the solution. The mixture was stirred rapidly in the beginning and slowly after the reaction commenced. The progress of the reaction was measured from time to time by removal of a small sample of solution from the reaction mixture and determined by its sodium naphthalene content after dilution with ethanol, by titration with standard hydrochloric acid using methyl red as indicator. The formation of sodium naphthalene (green colored solution) was complete in

$1\frac{1}{2}$ h . for the lower quantity and 3 h . for the higher quantity. Solution of sodium naphthalene was thus prepared freshly for every reaction.

Reaction of dibenzyl mercury with sodium naphthalene at room temperature (30°C), under nitrogen atmosphere.

(1) Reaction with equimolar amounts of dibenzyl mercury and sodium naphthalene, reaction time 30 min.

A solution of dibenzyl mercury (1.910 g ; 5×10^{-3} mol) in 30 ml dry THF was placed in a 3-necked 250 ml RB flask, provided with a gas inlet tube, a pressure equalizing dropping funnel and a condenser connected to a mercury trap. The contents of the flask were flushed with dry nitrogen gas for 30 min under magnetic stirring. Sodium naphthalene (5×10^{-3} mol) prepared as above was added through the dropping funnel slowly, with continuous stirring. The solution turned greenish-grey in color, due to the separation of finely divided metallic mercury. The reaction was allowed to proceed further for a period of 30 min. and the reaction mixture then added to a 1% solution of hydrochloric acid (200 ml). This solution was passed through a one inch column of celite to remove the precipitated mercury. Celite column was washed with further 100 ml of 1% hydrochloric acid and then with ether. The original solution together with the washings was then extracted with five, 50 ml portions of ether. The ethereal extract was washed with water, dried over anhydrous MgSO_4 , filtered and concentrated

carefully at room temperature under reduced pressure. The volume of the concentrated ethereal extract was made upto 50 ml and this mixture of products was analysed by GLC using a 10% SE-30 on Crom P(85-100M) column of 2m length. The products were identified by comparison of their retention times with those of the authentic samples and their yields determined by comparison of the peak areas with those from equal aliquots of standard solutions of authentic samples in ether. The yields of various products identified were: toluene (16%) and naphthalene (85%). The reaction mixture was then chromatographed over a column of silica-gel (100-200M). Elution of the column with petroleum ether (b.p. 60^o-80^oC) yielded a mixture of bibenzyl and naphthalene. This mixture was dissolved in ether (50 ml) and analysed by GLC as described above. The yields of the two products were estimated to be naphthalene (85%) and bibenzyl (5%). Elution of the column with a mixture of petroleum ether (b.p. 60^o-80^oC) and benzene in the ratio 3:1 yielded dibenzyl mercury (1.4g; ca. 76%); m.p. 110^oC; lit. m.p. 111^oC. The compounds were characterised by mixed melting point technique and comparison of their IR spectra with those of the authentic samples.

(2) Reaction with equimolar amounts of dibenzyl mercury and sodium naphthalene; reaction time -360 min.

To a solution of dibenzyl mercury (1.910g; 5×10^{-3} mol) in 30 ml dry THF under nitrogen atmosphere was added sodium

naphthalene (5×10^{-3} mol) prepared in 30 ml THF and the reaction allowed to proceed for 360 min. The mixture was worked up as described in 1. . . GLC analysis and separation of the mixture of products on silica-gel column, as described for previous reaction yielded toluene (21%); naphthalene (90%), bibenzyl (7%) and unreacted dibenzyl mercury (1.337g; ca. 70%).

(3) Reaction of dibenzyl mercury with sodium naphthalene in molar ratio 1:2; reaction time-30 min.

To a solution of dibenzyl mercury (1.910g; 5×10^{-3} mol) in dry THF (30 ml), kept at room temperature under nitrogen atmosphere, was added sodium naphthalene (0.01 mol) prepared in 30 ml of THF. Reaction mixture was worked up in the usual manner after 30 min. Metallic mercury was removed by filtration through celite and the resulting reaction mixture extracted with ether (5x50 ml). The ethereal extract was washed with water, dried, filtered and concentrated in the usual manner. GLC analysis and separation of product mixture on silica gel (100-200M) column, yielded toluene (65%), naphthalene (90%) and bibenzyl (31%). Not even a trace of the starting dibenzyl mercury was detected.

(4) Reaction with equimolar amounts of dibenzyl mercury and sodium naphthalene, in the presence of one mole equivalent of naphthalene; reaction time-30 min.

In a 3-necked RB flask mounted on a magnetic stirring base was placed dibenzyl mercury (1.910g ; 5×10^{-3} mol) and naphthalene

(0.64g; 5×10^{-3} mol) in dry THF (30 ml). The system was flushed with dry nitrogen and sodium naphthalene (5×10^{-3} mol) prepared in 30 ml of THF was added through a pressure equalizing dropping funnel. The reaction was worked up after 30 min. as described for the reaction 1. GLC analysis and column chromatography of the reaction mixture in the usual manner, yielded, toluene (12%), naphthalene (92%; based on the total of the amounts added as sodium naphthalene and naphthalene), bibenzyl (5%) and dibenzyl mercury (1.566g; 82%).

(5) Reaction of dibenzyl mercury with sodium naphthalene in molar ratio 1:2, in the presence of naphthalene (one mole equivalent of bibenzyl mercury); reaction time-30 min.

In a 3-necked 250 ml RB flask, dibenzyl mercury (1.910g; 5×10^{-3} mol) and naphthalene (0.64g; 5×10^{-3} mol) in dry THF (30 ml) were placed. The flask was maintained at room temperature (30°C) and the contents flushed with nitrogen. Sodium naphthalene (0.01 mol) contained in 30 ml of THF was then added through a pressure equalizing dropping funnel. The reaction was worked up after 30 min. as described for the reaction 1. GLC analysis and column chromatography of the reaction mixture, as described in the previous experiments, yielded toluene (58%), naphthalene (90%; based on the total amount added in the form of sodium naphthalene and as naphthalene), bibenzyl (32%) and unreacted dibenzyl mercury (0.160g; ca. 8%).

(6) Reaction of dibenzyl mercury with sodium naphthalene in molar ratio 1:2, in the presence of cumene; reaction time 30 min.

A solution of dibenzyl mercury (1.910g; 5×10^{-3} mol) and cumene (12g; 0.1 mol) in dry THF (30 ml) was placed in a 3-necked RB flask, mounted over a magnetic stirring base and maintained at 30°C. The contents of the flask were flushed with dry nitrogen for 30 min. and sodium naphthalene (0.01 mol) added through a pressure equalizing dropping funnel. The reaction mixture was worked up as usual after 30 min. On GLC analysis and separation of the products by column chromatography, the distribution of products was found to be: toluene (71%) naphthalene (0.556g; 87%), bibenzyl (27%) besides an unestimated amount of cumene. No dibenzyl mercury was detected among the products.

Reaction with equimolar amounts of dibenzyl mercury and sodium naphthalene, in the presence of MgBr_2 and subsequent treatment with benzophenone.

(1) Preparation of MgBr_2 : Magnesium (0.24g; 0.01g-atom) and THF (10 ml) were taken in a 3-necked flask equipped with a magnetic stirring device, a gas passing adapter, a condenser, and a pressure equalizing dropping funnel. The contents of the flask were kept under dry nitrogen atmosphere and 1,2-dibromoethane (1.88g; 0.01 mol) in 20 ml of dry THF slowly added through the dropping funnel. After completing the addition, stirring was continued for 1 h during which MgBr_2 was formed.

(ii) Isolation of benzyl diphenyl carbinol:

After work up of the reaction mixture with dilute hydrochloric acid, the mixture was extracted with ether. The ethereal extract was washed with water, dried (MgSO_4), and evaporated to remove the solvent. The resultant crude solid was washed with petroleum ether (b.p. $60-80^\circ\text{C}$) when soluble and insoluble portions were separated. The insoluble portion, on washing with ether, again gave one soluble and the other insoluble portion. The ether soluble portion, on removal of solvent yielded the carbinol which was characterized by elemental analysis, and comparison of m.p. and mixed m.p. with that of authentic samples.

(7) Reaction of dibenzyl mercury and sodium naphthalene in the presence of MgBr_2 and subsequent treatment with benzophenone:

A solution of dibenzyl mercury (1.910g; 5×10^{-3} mol) in 20 ml of THF was added to the flask containing MgBr_2 , through the dropping funnel. Dry nitrogen gas was passed through this mixture for 30 min. Sodium naphthalene (0.005 mol) contained in 30 ml of dry THF was added slowly to this reaction mixture and the contents of the flask stirred for 30 min, after which a solution of benzophenone (1.8g; 0.01 mol) in 20 ml THF was added. The contents of the flask were stirred for 4 h at room temperature. The mixture was then poured into 1% hydrochloric acid and worked up as usual. TLC analysis of the reaction mixture showed a spot

corresponding to benzyldiphenyl carbinol as established by comparison with an authentic sample. GLC analysis and column chromatography of the reaction mixture as usual yielded toluene (15%), naphthalene (0.56g; 89%), bibenzyl (5%), benzyldiphenyl carbinol (5%) and dibenzyl mercury (1.413g; 74%) besides unreacted benzophenone.

Reactions of diphenyl mercury with sodium naphthalene at room temperature (30°C) under nitrogen atmosphere.

(8) Reaction with equimolar amounts of diphenyl mercury and sodium naphthalene; reaction time-30 min.

A solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in 30 ml of dry THF was placed in a 3-necked 250 ml RB flask. The contents of the flask were flushed with nitrogen for 30 min under magnetic stirring. Sodium naphthalene (5×10^{-3} mol) contained in 30 ml of THF was added through a pressure equalizing dropping funnel slowly with continuous stirring. The reaction mixture was worked up after 30 min., as usual. GLC analysis of the reaction mixture using a 10% SE-30 Crom-P (85-100M) column of 2m length by the calibration method as described for reaction 1, yielded benzene (31%) and naphthalene (88%). The reaction mixture was charged over a silica gel (100-200M) column. Elution with petroleum ether (b.p. 60°C-80°C) yielded a mixture of naphthalene and biphenyl, which on GLC analysis, yielded naphthalene (88%) and biphenyl (6%). Elution of the column with a mixture of

petroleum ether (b.p. 60° - 80° C) and benzene in the ratio 3:1, yielded diphenyl mercury (1.079g; 61%); m.p. 124° C; lit.m.p. 125° C. The compounds were characterised by the mixed melting point techniques, GLC and comparison of their IR spectra with those of the authentic samples.

(9) Reaction with equimolar amounts of diphenyl mercury and sodium naphthalene; reaction time-360 min.

To a solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in 30 ml of dry THF under nitrogen atmosphere was added sodium naphthalene (5×10^{-3} mol) prepared in 30 ml of THF and the reaction allowed to proceed for 360 min. The reaction was worked up as usual, by adding it to 1% hydrochloric acid. After filtration through celite, to remove the separated mercury, the reaction mixture was extracted with ether (5x50 ml). The combined ethereal extracts were washed with water, dried, filtered, and concentrated. GLC analysis and separation of the product mixture on a silica gel column yielded benzene (34%), naphthalene (93%), biphenyl (7%) and unreacted diphenyl mercury (1.008g; 57%).

(10) Reaction of diphenyl mercury with sodium naphthalene in molar ratio 1:2; reaction time-30 min.

Sodium naphthalene (0.01 mol) prepared in 30 ml of THF was added to a solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in dry THF (30 ml) under nitrogen atmosphere at room temperature (30° C).

The reaction mixture was worked up after 30 min, in the usual manner. Analysis of the mixture of products by GLC and separation by chromatography on a silica-gel column, yielded, benzene (80%), naphthalene (92%) and biphenyl (18%). Not even a trace of unreacted biphenyl mercury was obtained.

(11) Reaction with equimolar amounts of diphenyl mercury and sodium naphthalene in the presence of one mole equivalent of naphthalene; reaction time 30 min.

In a 3-necked 250 ml RB flask, mounted over a magnetic stirring base, was placed diphenyl mercury (1.77g; 5×10^{-3} mol) and naphthalene (0.64g; 5×10^{-3} mol) dissolved in 30 ml of dry THF. The reaction system was flushed with dry nitrogen and then, sodium naphthalene (5×10^{-3} mol) prepared in 30 ml THF added through a pressure equalizing dropping funnel. The reaction mixture was worked up after 30 min, in the usual manner. GLC analysis and column chromatography of the reaction mixture as described in the reaction 1, yielded, benzene (24%), naphthalene (90%; based on total amount added in the form of sodium naphthalene and as naphthalene), biphenyl (5%), and unreacted diphenyl mercury (1.20g; 68%).

Reaction with equimolar amounts of diphenyl mercury and sodium naphthalene in the presence of MgBr_2 , to detect the possible formation of phenyl anions.

Preparation of MgBr_2 : MgBr_2 was prepared from magnesium (0.24g; 0.01g-atom) and 1,2-dibromoethane (1.88g; 0.01 mol) in 30 ml of THF as described earlier.

(12) Reaction of diphenyl mercury and sodium naphthalene in the presence of MgBr_2 and subsequent treatment with benzophenone:

A solution of diphenyl mercury (1.77g ; 5×10^{-3} mol) in 20 ml of THF was added to the flask containing MgBr_2 prepared in the previous experiment. Dry nitrogen gas was passed through this mixture for 30 min. Sodium naphthalene (5×10^{-3} mol) contained in 30 ml of dry THF was added slowly to this reaction mixture and the contents of the flask stirred for 30 min. after which a solution of benzophenone (1.8g ; 0.01 mol) in 20 ml of THF was added. The contents of the flask were stirred for 4 hr at room temperature. The mixture was then poured into 1% hydrochloric acid (200 ml) and worked up as usual. TLC analysis of the reaction mixture indicated the presence of triphenyl carbinol, as established by comparison with an authentic sample. GLC analysis and column chromatography of the reaction mixture in the usual manner, yielded benzene (22%), naphthalene (90%), biphenyl (6%), triphenylcarbinol (7%) and starting diphenyl mercury (1.11g ; 63%), besides unreacted benzophenone.

Reactions of phenyl p-tolyl mercury with sodium naphthalene at room temperature (30°C) under nitrogen atmosphere.

(13) Reaction with equimolar amounts of phenyl p-tolyl mercury and sodium naphthalene, reaction time-30 min.

In a 3-necked 250 ml RB flask, mounted over a magnetic stirring base, a solution of phenyl p-tolyl mercury (1.840g; 5×10^{-3} mol) in 30 ml of dry THF was placed. The contents of the flask were flushed with dry nitrogen for 30 min. sodium naphthalene (5×10^{-3} mol) contained in 30 ml of dry THF was slowly added to the above solution, through a pressure equalizing dropping funnel, with continuous stirring. The reaction mixture was worked up after 30 min. in the usual manner. GLC analysis of the mixture of products using a 10% SE-30 on Crom-P (85-100M) column of 2m length, by the calibration method, yielded, toluene (10%), benzene (15%), naphthalene (85%). The reaction mixture was chromatographed on a silica-gel (100-200M) column. Elution of the column with petroleum ether (b.p. 60°-80°C) yielded naphthalene (0.5440g; 85%). Diphenyl mercury (4%; 0.07g) and p-p'-ditolyl mercury (5% ; 0.09g). Further elution of the column with the same solvent gave 0.241g of a complicated mixture of biaryls which on attempted GLC analysis appeared to consist of biphenyl (ca. 4% yield), isomeric monomethyl-biphenyls (ca. 6%) and isomeric bi-tolyls (ca. 3%). Elution of the column with a mixture of petroleum ether (b.p. 60-80°C) and benzene in the ratio 3:1 yielded 1.26g of a mixtures of diaryl mercury compounds which by means of elemental analysis on standard

samples of mixtures of these compounds was found to correspond closely to the composition-phenyl p-tolyl mercury (51%), diphenyl mercury (5%) and p,p'-ditolyl mercury (5%). Elution of the column with ethyl acetate yielded a pasty mass which could not be analysed.

(14) Reaction of phenyl p-tolyl mercury with sodium naphthalene in molar ratio 1:2; reaction time-30 min.

To a solution of phenyl p-tolyl mercury (1.840g; 5×10^{-3} mol) in a 3-necked 250 ml RB flask, sodium naphthalene (0.01 mol) contained in 30 ml of THF was added. The reaction mixture was worked up after 30 min. in the usual manner. GLC analysis and separation of the product mixture on silica-gel column, as described in the previous experiment, yielded, benzene (41%), toluene (26%), and naphthalene (91%) and 0.533g of a complicated mixture of diaryls which on attempted GLC analysis appeared to consist of biphenyl (ca. 9%), isomeric monomethyl biphenyls (ca. 13%) and isomeric bitolyls (ca. 7%). Not even a trace of the starting material could be detected. Small quantity of an additional pasty mass recovered could not be analyzed.

B: Reaction of dibenzyl mercury with lithium aluminium hydride (LAH) at room temperature (30°C) under initial nitrogen atmosphere.

(1) Reaction with equimolar amounts of dibenzyl mercury and LAH; reaction time-30 min.

In a 3-necked 250 ml RB flask mounted over a magnetic stirring base, and connected to a nitrogen gas cylinder through a purifier, to a gas collector through a mercury trap and a pressure equalizing dropping funnel, was placed a solution of dibenzyl mercury (1.910g; 5×10^{-3} mol) in dry THF (30 ml). The solution was purged with nitrogen gas with continuous stirring. Lithium aluminium hydride (0.19g; 5×10^{-3} mol) contained in dry THF (30 ml) was added through the dropping funnel. Hydrogen gas (52 ml as at NTP, after accounting for the gas evolved in a control experiment under identical reaction conditions) was evolved. The reaction mixture turned grey due to the separation of mercury in finely divided form. The reaction mixture was worked up after 30 min, by the addition of distilled water (50 ml), followed by the addition of 2% hydrochloric acid (50 ml). The mercury produced in the reaction was removed from the mixture of products by filtration of the reaction mixture through celite. The reaction mixture was extracted with 5x50 ml portions of diethyl ether. The combined ethereal extracts were washed with water, dried over anhydrous MgSO_4 , filtered and concentrated carefully at room temperature under reduced pressure, to a volume of 50 ml. The

crude mixture was then analyzed by GLC using a 10% SE-30 on Crom-P(85-100M) column of 2m length, and the products identified by comparison of their retention times with those for the authentic samples. The product yields were obtained by a comparison of the peak areas with those of the authentic samples. Thus, toluene (64%) was identified to have formed. The reaction mixture was chromatographed over silica-gel (100-200M) column. Elution with petroleum ether (b.p. 60°-80°C) yielded dibenzyl (0.61; ca. 32%) m.p. 52°C; lit. m.p. 52.5°C. Further elution of the column with a mixture of petroleum ether (b.p. 60°-80°C) and benzene in various ratios such as 3:1, 2:1 and pure benzene yielded nothing. Elution with pure ethyl acetate yielded a pasty mass which could not be analyzed. Not even a trace of the starting dibenzyl mercury was detected. The compounds were characterized by the mixed melting point technique and GLC.

(2) Reaction of dibenzyl mercury with LAH in molar ratio 2:1; reaction time-30 min.

Addition of LAH (0.1g; 0.0025 mol) contained in 30 ml of dry THF to a solution of dibenzyl mercury (1.910g, 5×10^{-3} mol) in 30 ml of dry THF kept at room temperature (30°C) under nitrogen atmosphere, resulted in the evolution of 47 ml of hydrogen gas (as at NTP). The reaction mixture was worked up after 30 min in the usual manner. GLC analysis and separation of the products from the mixture by column chromatography as detailed in the

reaction 1(B), yielded toluene (54%), bibenzyl (0.497g; 23%) and dibenzyl mercury (0.362g; 19%).

(3) Reaction of dibenzyl mercury with LAH in molar ratio 4:1; reaction time-30 min.

The above reaction was repeated using LAH (0.05g; 0.00125 mol) and dibenzyl mercury (1.910g; 5×10^{-3} mol) in a total of 60 ml of dry THF. Hydrogen gas 30 ml (as at NTP) was evolved. The product distribution was determined to be: toluene (42%); bibenzyl (0.247g; ca. 12%); and unreacted dibenzyl mercury (0.611g; ca. 32%).

(4) Reaction of dibenzyl mercury with LAH in molar ratio 4:1; reaction time-300 min.

LAH (0.05g; 0.00125 mol) contained in 30 ml of THF was added to a solution of dibenzyl mercury (1.910g; 5×10^{-3} mol) in dry THF (30 ml) kept at room temperature, under nitrogen atmosphere. Reaction, which commenced immediately, was allowed to proceed for 300 min. Hydrogen gas 35 ml (as at NTP) was evolved. Mixture was worked up in the usual manner and the products obtained on GLC analysis and separation by column chromatography were: toluene (45%), bibenzyl (0.282g; 14%) and unreacted starting material dibenzyl mercury (0.515g; 27%).

- (5) Reaction of dibenzyl mercury with LAH in molar ratio 4:1; in the presence of cumene; reaction time-30 min.

In a 3-necked flask mounted over a magnetic stirring base was placed bibenzyl mercury (1.910g; 5×10^{-3} mol) and cumene (12g; 0.1 mol) dissolved in dry THF (30 ml). The system was thoroughly flushed with nitrogen. Thereafter, LAH (0.05; 0.00125 mol) contained in 30 ml of dry THF was added to the flask. Hydrogen gas 38 ml (as at NTP) was evolved during 30 min. GLC analysis and separation of the products by column chromatography, yielded; toluene (43%), bibenzyl (0.152g; ca. 8%), and starting material dibenzyl mercury (0.836g; 44%) along with an unestimated amount of cumene.

Reactions of diphenyl mercury and lithium aluminium hydride (LAH) at room temperature (30°C) under nitrogen atmosphere.

- (6) Reaction of diphenyl mercury with LAH in molar ratio 1:1; reaction time-30 min.

To a solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in dry THF (30 ml) kept at room temperature under nitrogen atmosphere, was added LAH (0.19g; 5×10^{-3} mol) contained in dry THF (30 ml). Hydrogen gas 55 ml (as at NTP after accounting for the gas evolved in a control experiment under similar conditions) was evolved. Reaction was allowed to proceed for 30 min, and then analyzed by GLC, before work up, when the presence of benzene (81%) was indicated. The reaction mixture was then worked up by the addition

of water followed by dil. HCl. After filtration through celite, the reaction mixture was extracted with diethyl ether (5x50 ml). The combined ethereal extracts were washed with water, dried (anhydrous $MgSO_4$), filtered and concentrated to a volume of 50 ml. GLC analysis using a 10% SE-30 on Crom-P (85-100M) column of 2m length, by the calibration method yielded benzene (81%) and biphenyl (0.7g; 15%). Not even a trace of the unreacted biphenyl mercury was detected.

(7) Reaction of diphenyl mercury with LAH in molar ratio 2:1; reaction time-30 min.

Reaction was carried out by adding LAH (0.1g; 0.0025 mol) contained in dry THF (30 ml) to a solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in dry THF (30 ml) under nitrogen atmosphere. The reaction proceeded with the evolution of hydrogen gas (50 ml as at NTP) and the mixture was worked up after 30 min, in the usual manner. GLC analysis of the product mixture yielded benzene (56%). Complete removal of the solvent gave a crude mixture, which on column chromatography over silica-gel column using petroleum ether (b.p. $60^\circ-80^\circ C$) gave biphenyl (0.195g; ca. 10%). Further elution of the column with petroleum ether (b.p. $60^\circ-80^\circ C$) and benzene in molar ratio 3:1 (v/v) gave diphenyl mercury (0.548g; 31%); m.p. $124^\circ C$; lit. m.p. $125^\circ C$. Biphenyl was also characterized by GLC and diphenyl mercury using mixed melting point technique.

- (8) Reaction of diphenyl mercury with LAH in molar ratio 4:1;
reaction time-30 min.

LAH (0.05g; 0.00125 mol) contained in 30 ml of dry THF was added to a solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in 30 ml of THF, under nitrogen atmosphere. Hydrogen gas (30 ml as at NTP) was evolved. The reaction mixture was worked up after 30 min, in the usual manner. GLC analysis and separation of the products using silica-gel column gave benzene (45%); biphenyl (0.141g; ca. 8%) and diphenyl mercury (0.761g; 43%), characterized by comparison with authentic samples and mixed melting point technique.

- (9) Reaction of diphenyl mercury with LAH in molar ratio 4:1;
reaction time-300 min.

Reaction was carried out by the addition of LAH (0.05g; 0.00125 mol) contained in dry THF (30 ml) to a solution of diphenyl mercury (1.77g; 5×10^{-3} mol) in 30 ml of THF, under nitrogen atmosphere. Reaction was allowed to proceed for 300 min when 35 ml of hydrogen gas (as at NTP) was evolved. The reaction mixture was worked up by addition of distilled water followed by acidified water. The products were extracted from the reaction mixture with ether and the ethereal extract washed, dried, filtered and concentrated to give a crude mixture, which was analyzed by GLC and separated by means of column chromatography in the manner

described previously for the reaction (B8). The products obtained were: benzene (48%), biphenyl (0.159g; 9%) and diphenyl mercury (0.637g; 36%).

(10) Reaction of diphenyl mercury with LAH in molar ratio 1:1; in the presence of naphthalene; reaction time-30 min.

In a three necked RB flask mounted over a magnetic stirring base were placed diphenyl mercury (1.77g; 5×10^{-3} mol) and naphthalene (0.64g; 5×10^{-3} mol) dissolved in 30 ml of dry THF. The reaction system was flushed with nitrogen and LAH (0.19g; 5×10^{-3} mol) contained in 30 ml of dry THF was added to the flask. Hydrogen gas 60 ml (as at NTP) was evolved. On work up, GLC analysis by the calibration method and separation of the products by column chromatography, the yields of the products were found to be: benzene (46%), biphenyl (0.15g; 9%) and unreacted diphenyl mercury (0.708g; 40%).

(C) Reactions of phenyl p-tolyl mercury with LAH, at room temperature under nitrogen atmosphere.

(11) Reaction of phenyl p-tolyl mercury with LAH in molar ratio 1:1; reaction time-30 min.

LAH (0.19g; 0.005 mol) contained in dry THF (30 ml) was added to a solution of phenyl p-tolyl mercury (1.840g; 5×10^{-3} mol) in 30 ml of dry THF kept at room temperature (30°C) under nitrogen atmosphere. Hydrogen gas 60 ml (as at NTP, after accounting for

the gas evolved in a control experiment under identical conditions) was evolved. Reaction was worked up after 30 min by the addition of distilled water (50 ml) followed by 2% HCl. This mixture was extracted with ether (5x50 ml), after filtration through celite, and the ethereal extract washed with water, dried over anhydrous MgSO_4 and concentrated to a volume of 50 ml. GLC analysis of the product mixture by the calibration method yielded toluene (36%) and benzene (39%). The reaction mixture was then charged over a silica-gel column and the column eluted with petroleum ether (60°-80°C b.p.) to give 0.276g of a complicated mixture of biaryls which on attempted GLC analysis appeared to consist of biphenyl (ca. 5% yield), isomeric monomethyl biphenyls (ca. 7% yield) and isomeric bitolyls (ca. 3% yield). Further elution with petroleum ether (b.p. 60°-80°C) and benzene in the ratio 3:1 (v/v) indicated that the starting material, phenyl p-tolyl mercury was not present among the products even in traces. All the products were identified by comparison with authentic samples and mixed melting point technique.

(12) Reaction of phenyl p-tolyl mercury with LAH in molar ratio 2:1, reaction time 30 min.

To a solution of phenyl p-tolyl mercury (1.840g; 0.005 mol) in dry THF (30 ml), kept under nitrogen atmosphere was added LAH (0.1g; 0.0025 mol) contained in 30 ml of dry THF. Hydrogen gas 40 ml (as at NTP) was evolved. Reaction mixture was worked up

after 30 minutes. GLC analysis gave toluene (16%), benzene (24%). Column chromatography as described above also gave 0.202g of a complicated mixture of biaryls which on attempted GLC analysis appeared to consist of biphenyl (ca. 3% yield), isomeric monomethyl biphenyls (ca. 4%) and isomeric bitolyls (ca. 4%). Elution of the column finally with a mixture of petroleum ether (b.p. 60°-80°C) and benzene in the ratio of 1:3 (v/v) yielded 0.863g of a mixture of diaryl mercury compounds which by means of elemental analysis on standard samples of mixtures of these compounds was found to correspond closely to the composition-phenyl p-tolyl mercury (40%), diphenyl mercury (3%) and di-p,p'-tolyl mercury (5%).

(13) Reaction of phenyl p-tolyl mercury with LAH in molar ratio 4:1; reaction time-30 min.

Addition of LAH (0.05g; 0.00125 mol) contained in dry THF (30 ml) to a solution of phenyl p-tolyl mercury (1.840g; 0.005 mol) in dry THF (30 ml) under nitrogen atmosphere at room temperature liberated 10 ml (as at NTP) of hydrogen gas. On work up of the reaction and subsequent GLC analysis and separation of the products by column chromatography, as detailed in previous experiments, toluene (11%) and benzene (13%) along with 0.09g of a mixture of biaryls containing biphenyl (ca. 2%), isomeric monomethylbiphenyl (ca. 2%) and isomeric ditolyls (ca. 1%) and another mixture of diaryl mercury compounds presumably consisting of phenyl p-tolyl mercury (ca. 52%), diphenyl mercury (ca. 6%) and di-p-tolyl mercury (ca. 4%).

- (14) Control reaction of lithium aluminium hydride with cumene at room temperature under nitrogen atmosphere.

LAH (0.19g; 0.005 mol) contained in 30 ml of THF was added to a solution of cumene (0.6g; 0.005 mol) in 30 ml of THF kept at room temperature (30°C) under nitrogen atmosphere. No hydrogen gas was evolved. The reaction mixture was worked up after 30 min in the usual manner. On extraction and isolation, unchanged starting hydrocarbon was recovered quantitatively.

- (15) Control reaction of LAH with naphthalene at room temperature under nitrogen atmosphere.

To a solution of naphthalene (0.64g; 0.005 mol) in dry THF (30 ml) was added LAH (0.19g; 0.005 mol) contained in 30 ml of dry THF under conditions identical to that employed for the reaction 14. No hydrogen gas was evolved. On working up the reaction mixture after 30 min. in the usual manner, the unchanged starting hydrocarbon was recovered quantitatively.

II.5 References

1. F.C. Whitmore, "Organic Compounds of Mercury", Reinhold Publishing Corporation, New York, 1921.
2. Frankland, J. Am. Chem. Soc., 85, 361 (1953).
3. S. Winstein and Traylor, J. Am. Chem. Soc., 77, 3747 (1955).
4. F.C. Whitmore and W. Bernstein, J. Am. Chem. Soc., 60, 2626 (1938).
5. L.H. Gale, F.P. Jensen and J.A. Laughton, Chem. Ind., 118 (1960).
6. F.R. Jensen and R.J. Ouellette, J. Am. Chem. Soc., 83, 4477 (1961).
7. "Methods of Elemento-Organic Chemistry", A.N. Nesmeyanov and K.A. Kochesnikov (Eds.), Vol. 4, North-Holland Publishing Company, Amsterdam, 1967, Chapter 14.
8. C. Schorlemmer, Ann. Chem., 132, 243 (1864).
9. R. Otto, Ann. Chem., 154, 188 (1870).
10. a. M.S. Kharasch and M.W. Graffin, J. Am. Chem. Soc., 47: 1948 (1925).
 b. M.S. Kharasch and R. Marker, *ibid.*, 18: 3130 (1926).
 c. M.S. Kharasch and A.L. Flenner, *ibid.*, 54: 674 (1932).
 d. M.S. Kharasch, H. Pines, and J.H. Levine, J. Org. Chem., 3: 347 (1938-1939).
 e. M.S. Kharasch and S. Swartz, *ibid.*, 3: 405 (1938-1939).
 f. M.S. Kharasch, R.R. Legault, and W.R. Uprows, *ibid.*, 3, 409 (1938-1939).
11. G.F. Wright, Can. J. Chem., 30, 268 (1952).
12. W. Steinkopf, Justus Liebig's Annln. Chem., 413, 310 (1917).

13. M. Rausch, M. Vogel and H. Rosenberg, *J. Org. Chem.*, 22, 900 (1957).
14. I.T. Sskin, *Izv. Akad. Nauk. USSR, Otdel, Khim. Nauk*, 297 (1942).
15. J.D. Loudon, *J. Chem. Soc.*, 535 (1935).
16. L.D. Hurd and C.J. Morrissey, *J. Am. Chem. Soc.*, 77, 4658 (1955).
17. K. Icnikawa, H. Ouchi and S. Fukushima, *J. Org. Chem.*, 24, 1129 (1959).
18. F.R. Jensen and J.A. Landgrebe, *J. Am. Chem. Soc.*, 82, 1004 (1960).
19. H.J. Emeleus and R.W. Haszeldine, *J. Chem. Soc.*, 2953 (1949).
20. F.E. Paulik, S.I.F. Green and R.E. Pessy, *J. Organometal. Chem.*, 3, 229 (1965).
21. J.F. Garst, P.W. Myers and P.C. Lamb, *J. Am. Chem. Soc.*, 88, 4260 (1966).
22. W. Adams and J. Arce, *J. Org. Chem.*, 37, 507 (1972).
23. O.D. Sargent, *Tetrahedron Lett.*, 3279 (1971).
24. W.D. Clossen, J. Ji and S. Schulenberg, *J. Am. Chem. Soc.*, 92, 650 (1970).
25. P.R. Singh, A. Nigam and J.M. Khurana, *Tetrahedron Lett.*, 4753 (1980).
26. P.R. Singh, J.M. Khurana and A. Nigam, *Tetrahedron Lett.*, 2901 (1981).
27. P.R. Singh, J. Jayaraman and H.K. Singh, *Chem. and Ind.*, 311 (1977).

- 28.a. P.R. Singh and Alok Nigam, Unpublished results.
- b. Alok Nigam, Ph.D. Thesis, Indian Institute of Technology, Kanpur, India, 1975.
29. P.R. Singh and R.K. Khanna, Tetranedron Letters, 973 (1983).
30. P.R. Singh and R.K. Khanna, Tetranedron Letters, 1411 (1983).
31. R. Benesch and R.E. Benesch, J. Am. Chem. Soc., 73, 3391 (1951).
32. F.R. Jensen and R. Rickborn, "Electrophilic substitution of organomercurials", pp. 137-138, McGraw Hill Book Co., New York, 1968.
33. F.R. Jensen and L.H. Gale, J. Am. Chem. Soc., 81, 6337 (1959).

CHAPTER-III

N-BROMOSUCCINIMIDE OXIDATION OF α -HYDROXY CARBOXYLIC ACIDS AND THEIR SALTS

III.1 Abstract

Oxidative decarboxylation of α -hydroxy acids viz. glycolic acid, mandelic acid and benzoic acid and their salts using N-bromo succinimide (SNBr) in dry dimethylformamide (DMF) at reflux temperature have been studied with a view to understanding the mechanistic details. It was observed that the salts of the α -hydroxy acids reacted at a faster rate than the corresponding α -hydroxy acids under similar conditions. Carbonyl compounds were the common products of these reactions besides carbon dioxide, molecular bromine and succinimide. Similar oxidation of the potassium salt of benzoic acid has also been accomplished using p-nitrobenzene diazonium fluoroborate instead of SNBr as the oxidant. Reactions with SNBr using the two reactants in 1:1 ratio were largely incomplete; but doubling the quantity of the oxidant (SNBr)

resulted in the completion of the reaction under otherwise similar conditions.

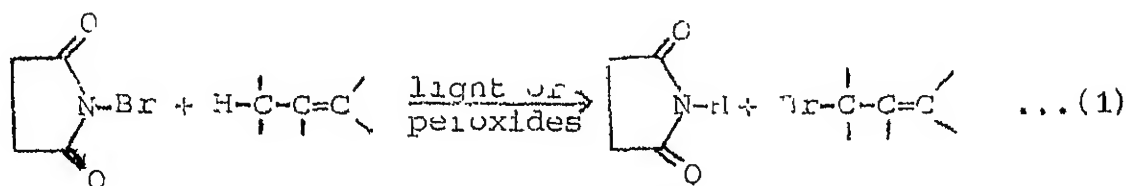
In view of these and other observations an electron transfer mechanism has been proposed which accounts for the experimental results. N-bromosuccinimide accepts an electron from the substrate α -hydroxy acid or its anion in the first step of fundamental importance. Succinimidyl anion, bromine atom and the radical derivable by the loss of an electron from the anion of the α -hydroxy acid serve as precursors of different products.

III.2 Introduction:

The utility of N-bromosuccinimide (SNBr) as a reagent for bromination¹ of a wide variety of organic compounds and as an oxidizing agent for the conversion of primary and secondary aliphatic alcohols to the corresponding aldehydes and ketones was recognized as early as 1942. Since then, a large number of reports on the use of this reagent has appeared in the literature but very little has been reported concerning the details of the mechanism of reactions of this reagent with various substrates.

A free radical chain mechanism for the substitution in allylic bromination of alkenes and benzylic bromination of alkyl aromatics using SNBr generally termed as Wohl-Ziegler reaction^{2,1} has been established, since, the reaction rate is accelerated by

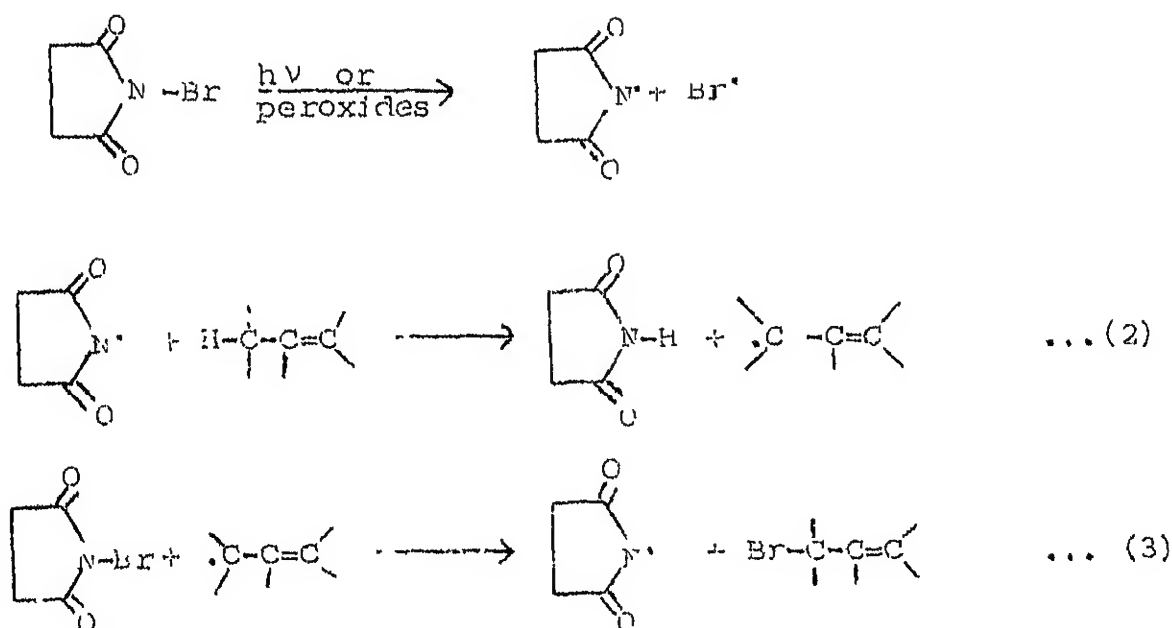
Free radical promoters such as peroxides and illumination of the reaction mixture and retarded in the presence of free radical inhibitors like oxygen and bromanil.³



A mechanism involving abstraction of the allylic hydrogen atom by the succinimidyl radical (Eqn.2) followed by the reaction of the resulting allyl radical with the brominating agent (Eqn.3) was reported by Bloomfield⁴ in 1944 as shown in Scheme III.1.

SCHEME III.1

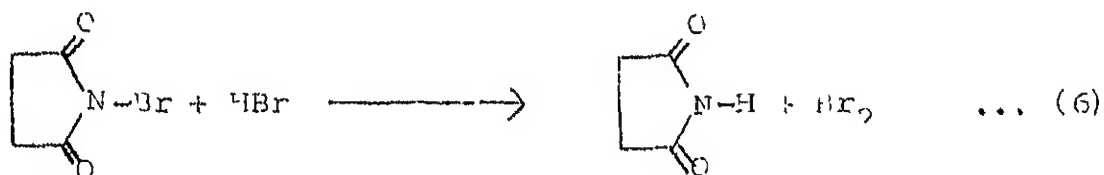
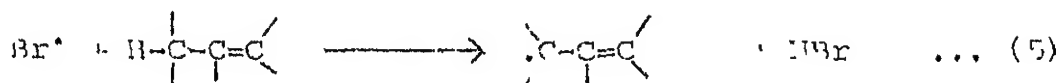
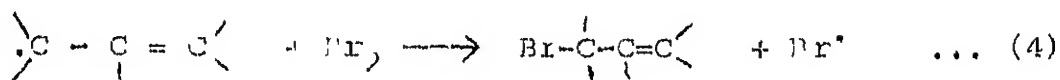
Bloomfield Mechanism:



The presently accepted mechanism for the reaction is one suggested by Goldfinger⁵ as outlined in Scheme III.2.

SCHEME III.2

Goldfinger Mechanism

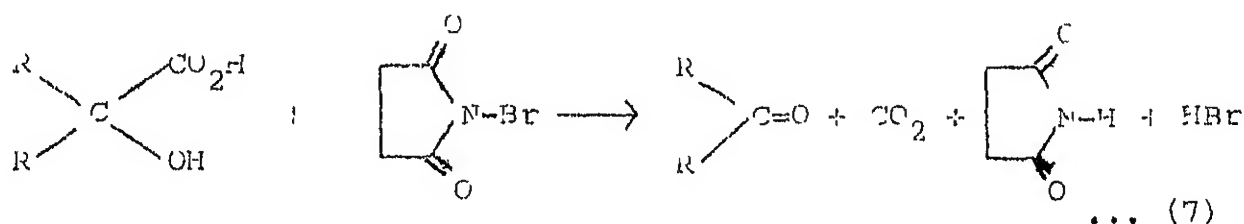


According to this mechanism, a minute amount of molecular bromine initially formed following the homolysis of N-Br bond in BrNBr serves as the brominating agent in the beginning. The bromine required for the subsequent reaction is supposed to be generated by a fast ionic reaction of hydrogen bromide with BrNBr ⁶.

Evidence supporting the Goldfinger mechanism is the similarity observed in the reaction rates of bromination of alkanes, alkyl aromatics and substituted toluenes with bromine and BrNBr ⁷. Other evidence supporting this mechanism comes from the observation that alkenes are brominated at the allylic position under free radical conditions if low bromine concentrations are

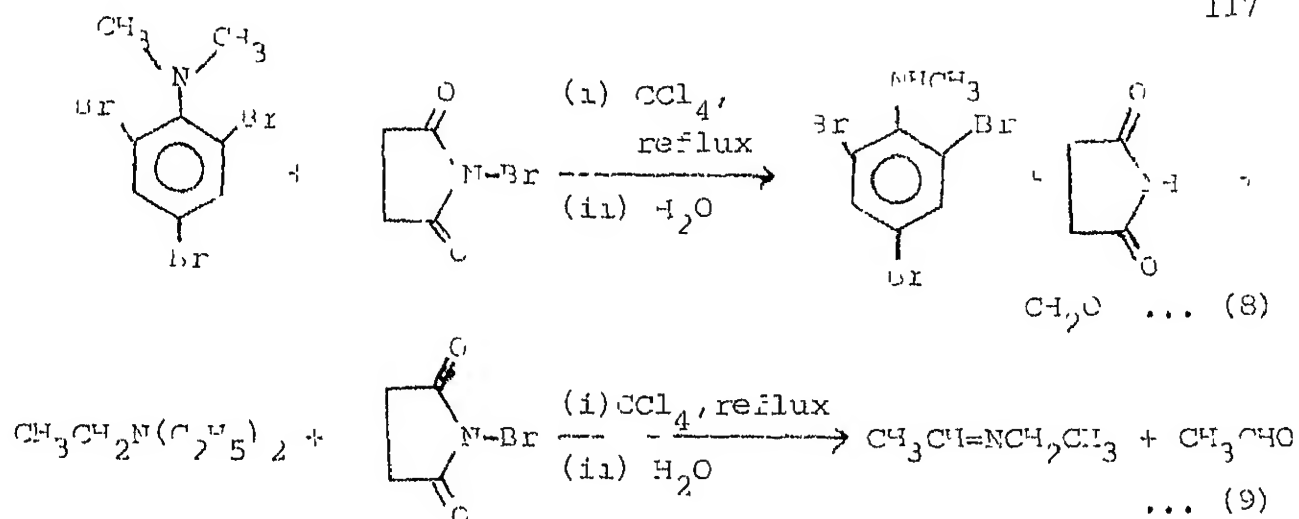
maintained⁸ and that large yields of trans-3-nexene^{8,9} are obtained on reaction of cis-3-nexene with just sufficient quantity of SNBr.

M. Z. Barakat¹⁰ et.al. have reported that SNBr reacts with α -hydroxy acids in not aqueous solutions to give aldehydes and ketones with the loss of one carbon atom (Eqn.7).

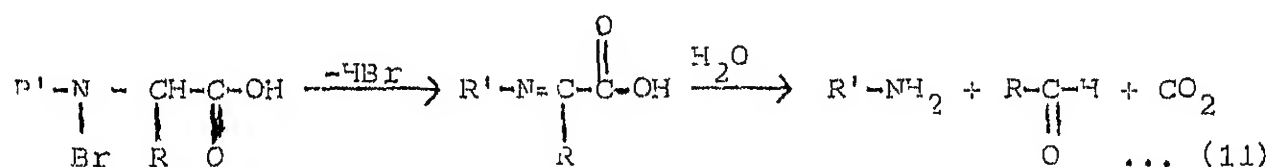
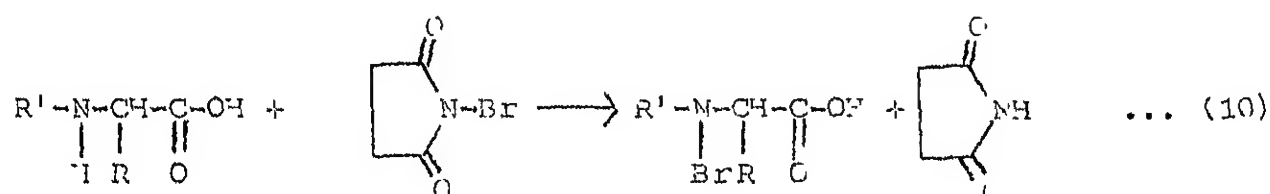


Primary and secondary alcohols can be oxidized by SNBr under mild reaction conditions in aqueous dioxane, acetone etc., to the aldehydes and ketones, respectively. Benzoin gave benzil in 95% yield and 9-fluoreinol gave 9-fluorenone in 89% yield.¹⁰

Oxidation of tertiary amines by SNBr was found to form, through the cleavage of a C-N bond in the amine, either an aldehydes and a secondary amines (Eqn.8) or an aldehyde and an enamines (Eqn.9), depending upon the structure of the original tertiary amine. The enamine is thought to be formed via the radical-cation of triethylamine.³



Oxidative degradation of α -amino acids with two moles of SNBr in aqueous solution at room temperature gives aldehydes with one less carbon atom, accompanied by evolution of CO_2 and N_2 .¹¹ This reaction involves C-C and C-N bond cleavages¹² (Eqns. 10 and 11).



SNBr reacts readily with benzophenone hydrazone, fluorenone-hydrazone and benzilmonohydrazone to yield the corresponding sym-diarylketazines in almost quantitative yields. Hydrazine hydrate reacts vigorously with SNBr to give nitrogen, hydrogen bromide and

succinimide. Phenylhydrazine reacts to give these substances and hydrazobenzene. With formic acid, SNBr gives carbon dioxide, hydrogen bromide and succinimide, while acetic acid does not react under similar conditions.

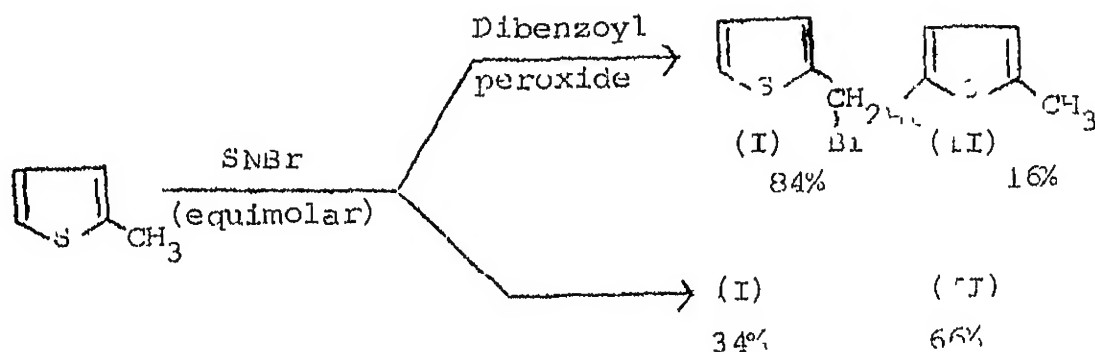
Complexes between N-bromosuccinimide and succinimide anion have been shown by J.E. Barry and Lennart Ebersson¹³, to be the intermediates in the reduction of SNBr . The electrochemical reduction of SNBr in acetonitrile is thought to generate succinimidyl radical (SN^{\bullet}) by means of the reaction shown below:



The intermediacy of the succinimide anion was demonstrated by trapping it with alkylating agents where the formation of N-alkyl succinimides was observed¹⁴.

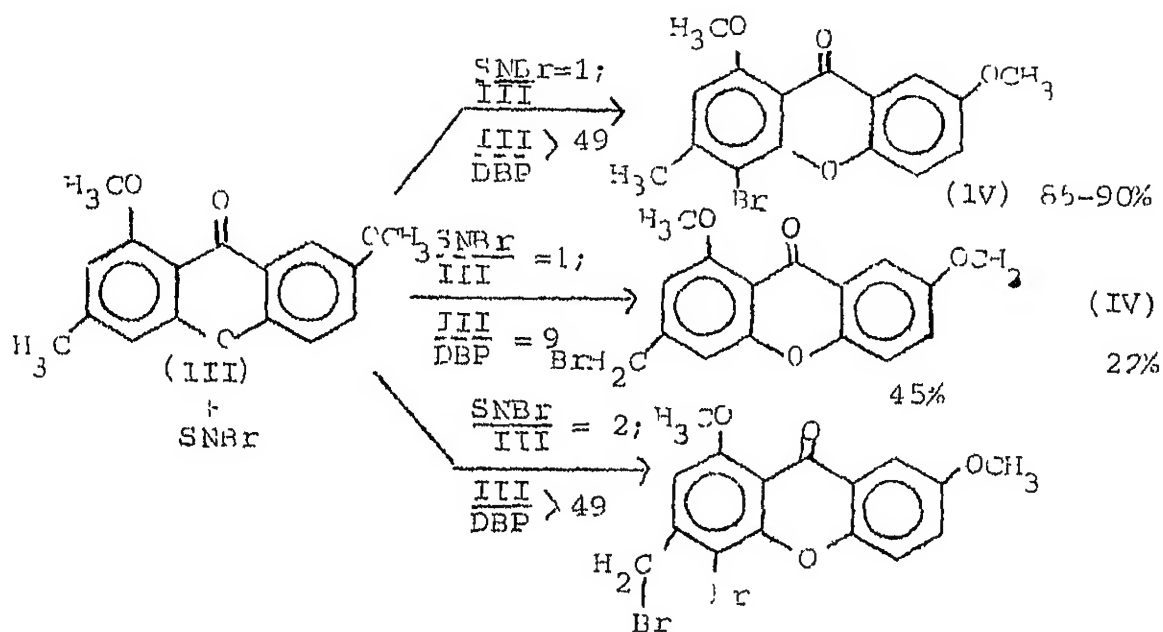
SNBr can affect the side-chain and/or ring bromination in various alkyl arenes under experimental conditions which promote free radical chain reactions (for example, reactions carried out in the presence of light and free radical initiators like dibenzoyl peroxide and azobisisobutyronitrile using CCl_4 as solvent).

2-Methyl thiophene, when reacted with S_NBr in 1.1 molar ratio in the presence of dibenzoyl peroxide, gave 2-bromomethyl thiophene(I) in 84% yield and 5-bromo-2-methyl thiophene(II) in 16% yield; whereas in the absence of the peroxide, 34% of I and 66% of II were obtained.¹⁵

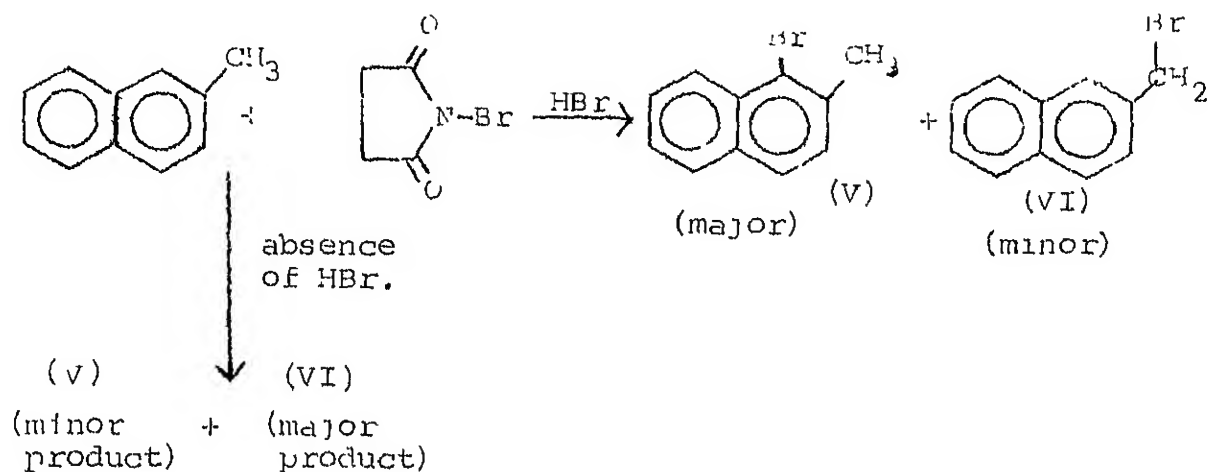


Similar results were obtained with 3-methylthiophene.¹⁶ G. Goisis¹⁷ has shown recently, that the amount of dibenzoyl peroxide (DBP) present in the reaction mixture affects the yields of side-chain vs ring bromination products obtained in the S_NBr bromination of 1,7-dimethoxy-3-methylxanthone (III), as shown in Scheme III.3.

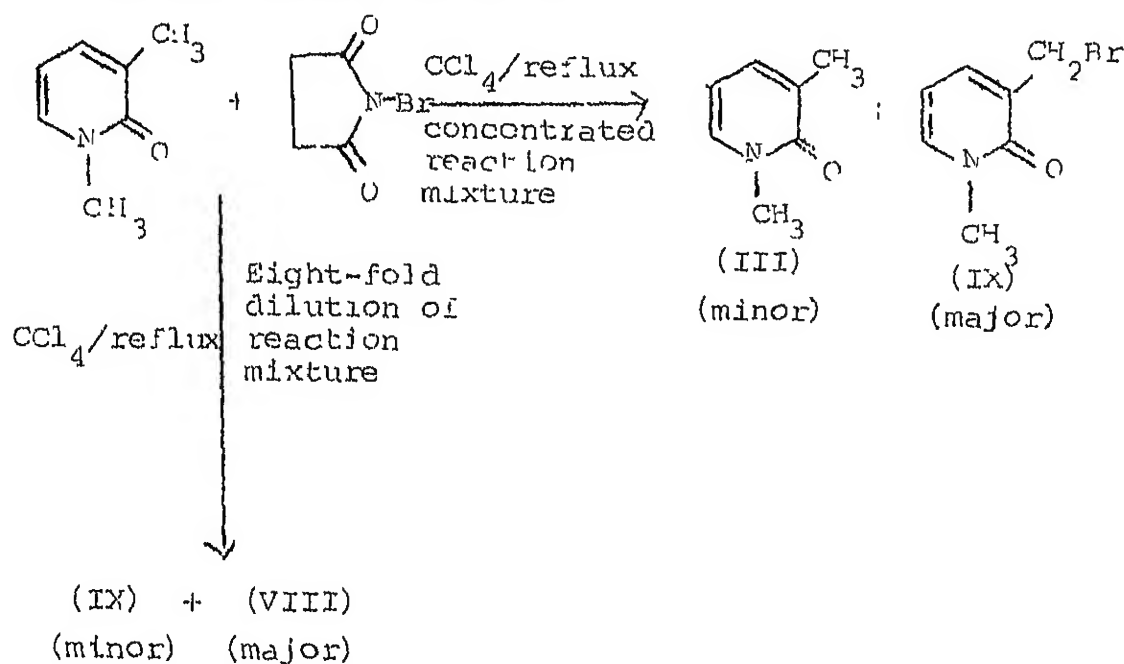
SCHEME III.3



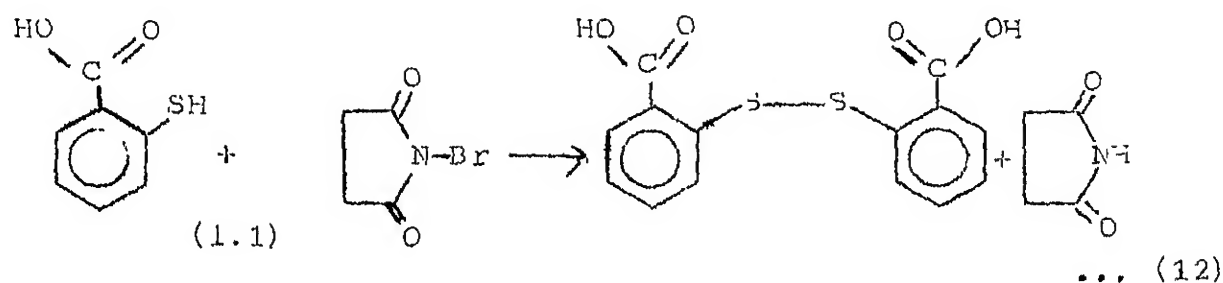
The presence or absence of a volatile impurity, is one of the factors which determines the course of these reactions.¹⁸ For example, HBr favours the formation of nuclear brominated product, 1-bromo-2-methyl-naphthalene in the bromination of 2-methyl naphthalene with SNBr .



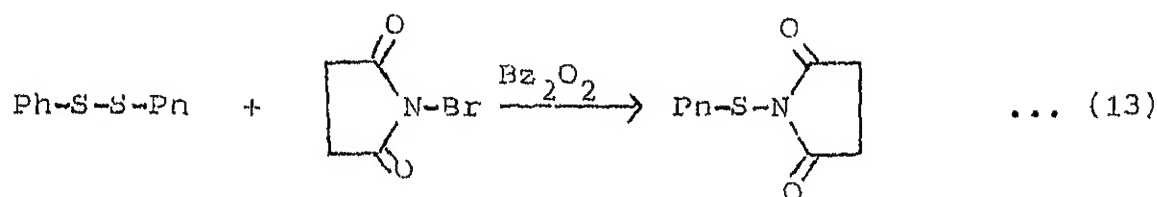
Quantity of solvent also influences the ring and side-chain brominations brought about by SNBr .¹⁹



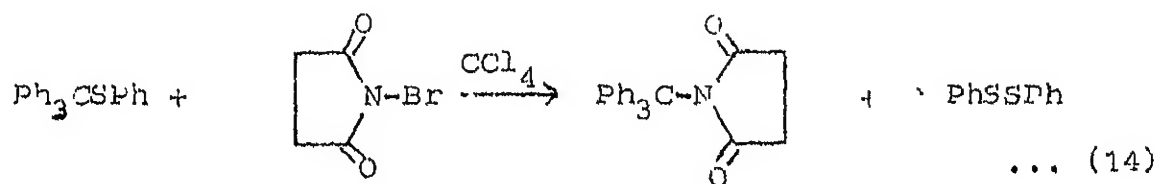
Equimolar quantities of SNBr in CCl_4 medium have been shown to oxidize mercapto groups to disulfides²⁰ (Eqn.12).



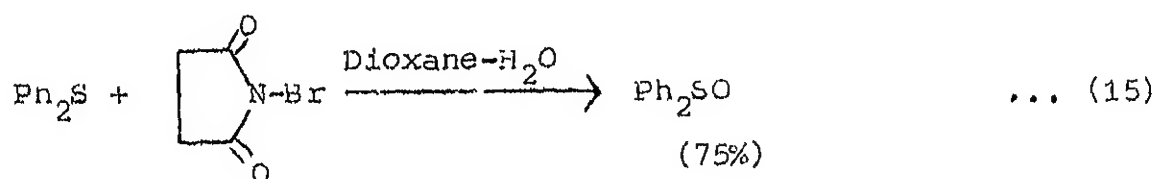
Oxidative cleavage of aromatic disulfides in dry CCl_4 in the presence of dibenzoyl peroxide (Bz_2O_2) was observed by W. Growbel²¹ (Eqn.13).



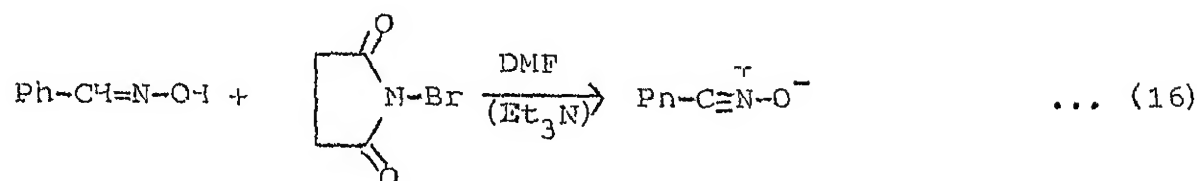
Oxidative cleavage of triphenylmethyl phenyl sulfide²² by SNBr takes place as shown in (Eqn.14).



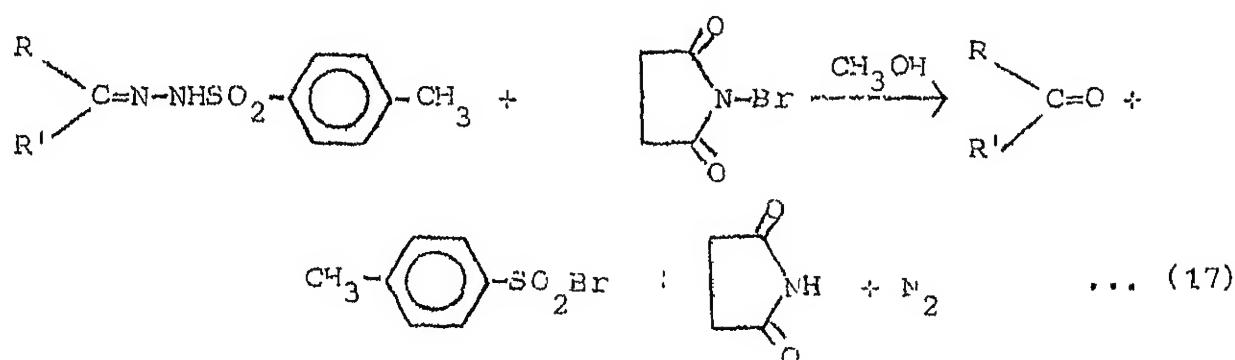
Aromatic sulfides react with SNBr in aqueous media giving high yields of the corresponding sulfoxides.²³ For example, see Eqn.15.



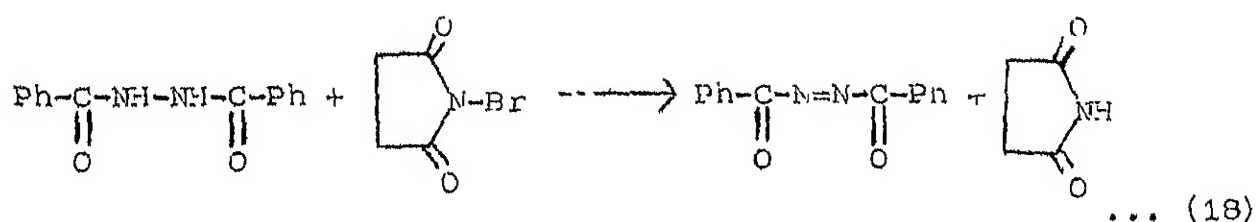
Oxidation of aldehyde oximes with S_NBr in dimethylformamide (DMF) gives nitrile oxides²⁴ (Eqn.16).



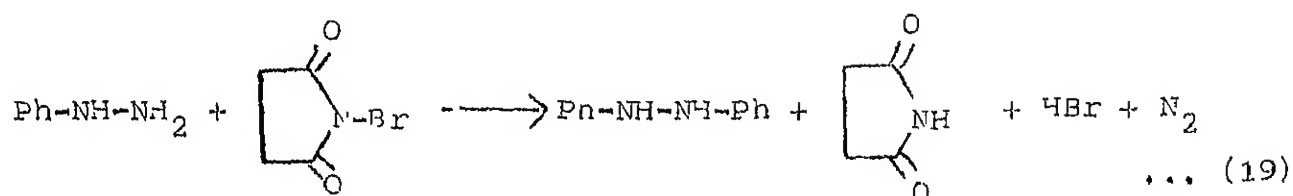
Tosylhydrazones can be converted to the parent carbonyl compounds on treatment with S_NBr²⁵ (Eqn.17).



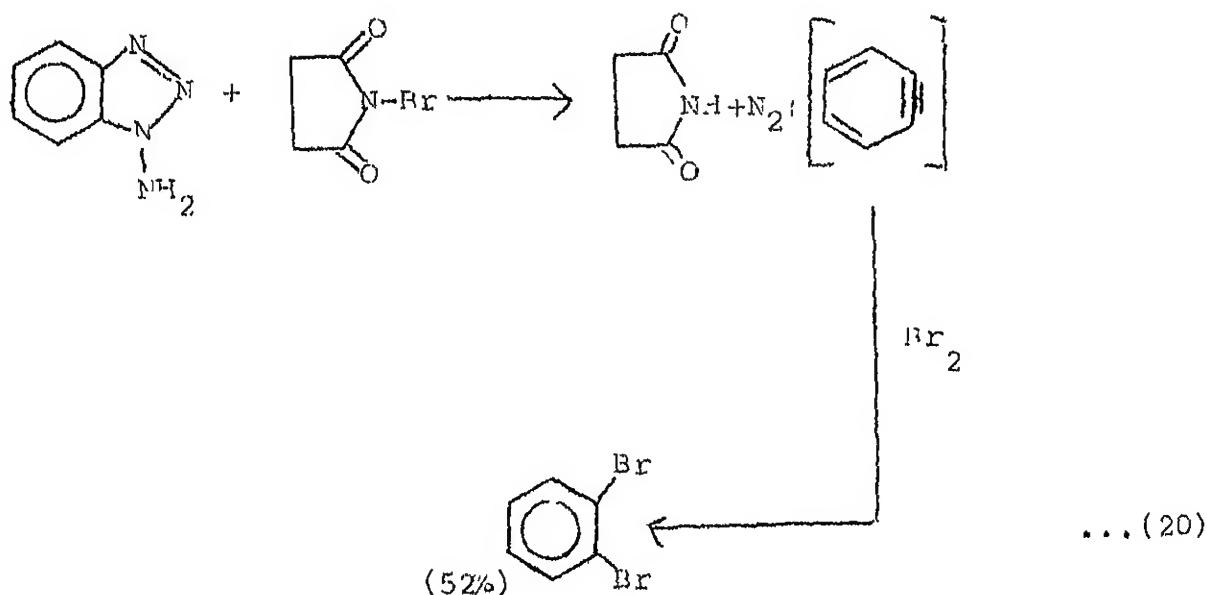
Symmetrical ketazines are formed when hydrazones are oxidised with S_NBr.²⁶ 1,2-Disubstituted hydrazines, on oxidation with S_NBr in inert solvents, give azo compounds as shown in (Eqn.18).



Phenylhydrazine is oxidised by SNBr to hydrazobenzene with evolution of N_2 gas.²⁶ (Eqn.19)

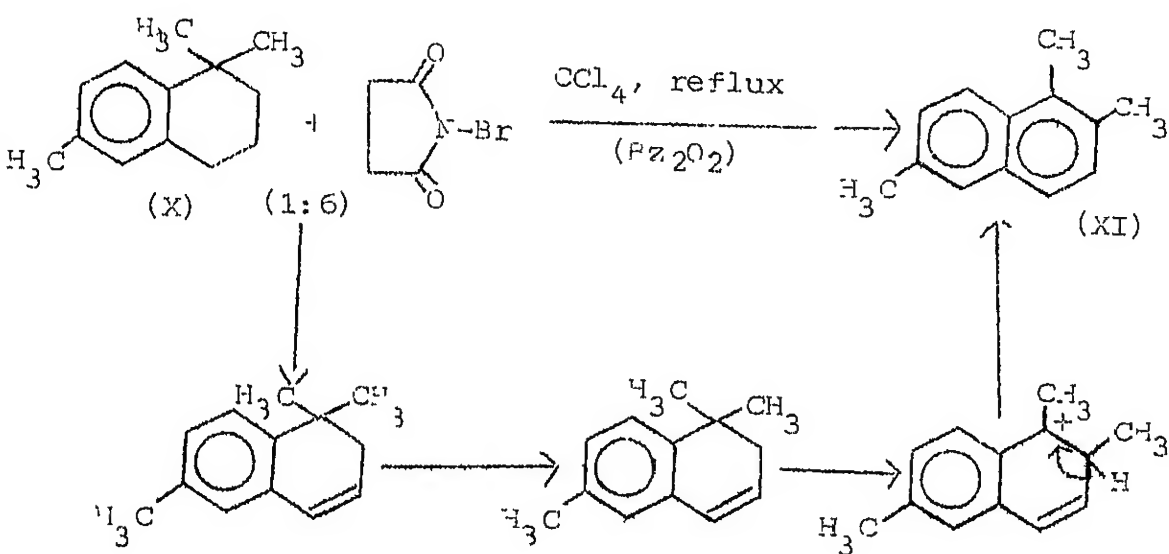


That benzyne intermediates are formed in the oxidation of 1-aminobenzotriazole²⁷ with SNBr was shown by trapping this intermediate by means of bromine addition (Eqn.20).

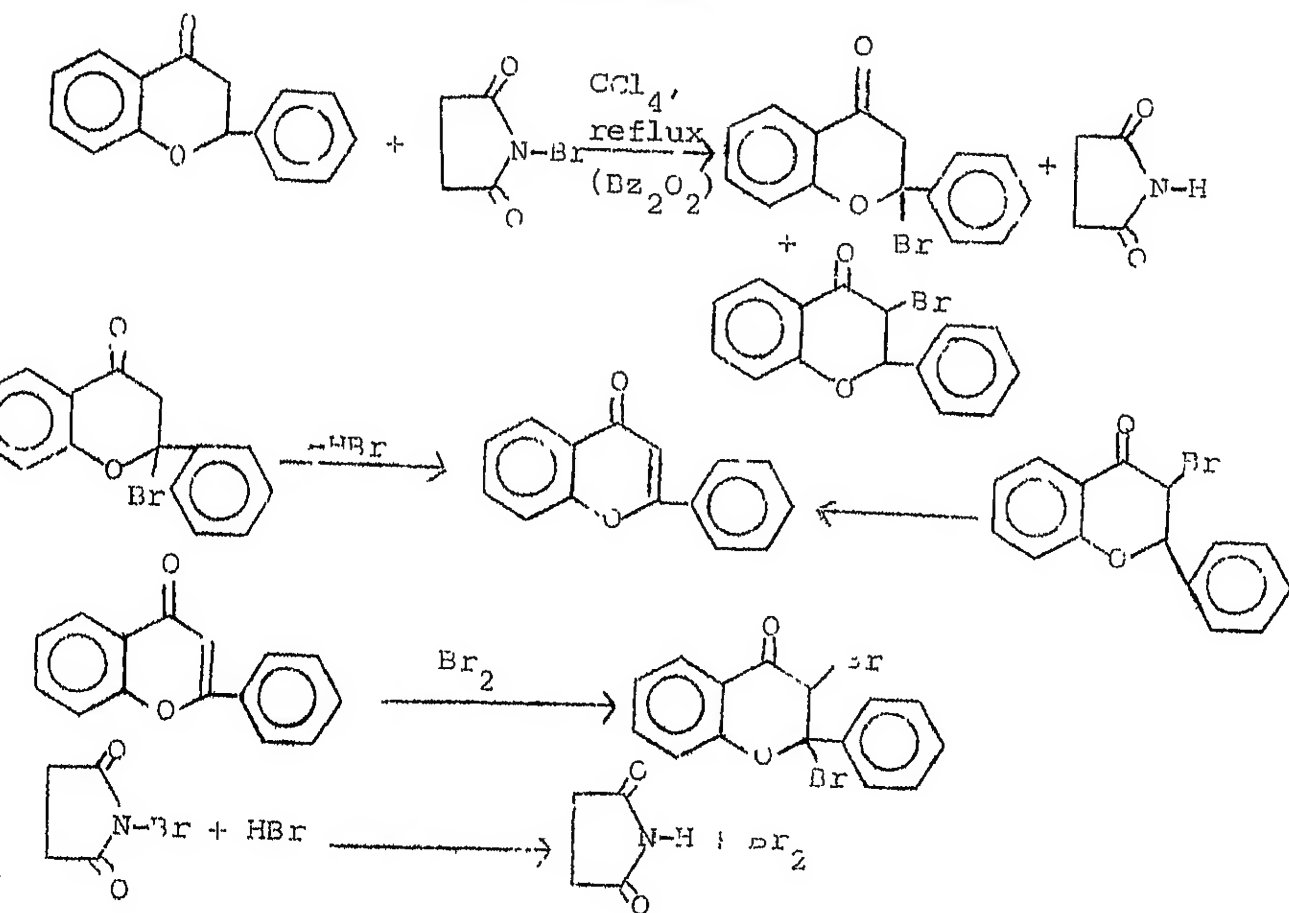


Schemes III.4²⁷ and III.5²⁸ illustrate a few of the dehydrogenation reactions of organic compounds accomplished using an excess of SNBr .

SCHEME III.4



SCHEME III.5



The thermooxidative destruction³⁰ of 1,4,5,8-naphthalene tetracarboxylic, fluorenone carboxylic, 1,8-naphthalene dicarboxylic, phthalic and diphenonic acids and their potassium or sodium salts has also been studied. All free acids were decomposed to CO_2 and H_2O at $200-500^\circ\text{C}$; but the salts yielded other acids, such as mellophanic, σ -naphthoic & hemimellitic acids with ring cleavage and decarboxylation.

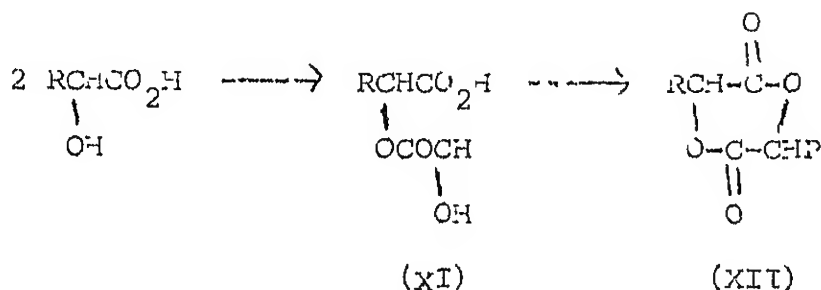
Tetrachloro (or bromo)phthalic acid²⁹ or anhydride and 3-nitrophthalic acid were decarboxylated to corresponding benzoic acid when refluxed in DMF. Under similar conditions, 1,8-naphthalene dicarboxylic acid and its nitro derivatives gave corresponding anhydrides.

Carlsen has reported oxidative decarboxylation of α -hydroxy carboxylic acids with sodium hypochlorite in acidic medium giving the next lower homologous carboxylic acid. In the absence of the acid and in $\text{H}_2\text{O}-\text{Et}_2\text{O}$ medium, aldehydes and ketones were observed to be quantitatively formed. Thus, PhCH(OH)COOH and NaOCl gave 95% of PhCHO while PhCMe(OH)COOH and NaOCl gave 93% of PhCMe .

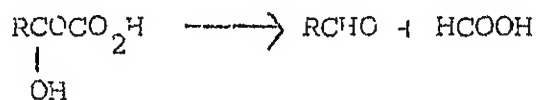
Alcohols were prepared by photochemical decarboxylation of α -hydroxy carboxylic acids when irradiation of the acids was carried out in the presence of a peroxide or an azo compound from radical initiators. Thus, $\text{HO}_2\text{CCHMeOH}$ was irradiated for 26 h. in the presence of $\text{UO}_2(\text{OAc})_2$ and BzOOH to yield 48% of EtOH .

α -Hydroxy acids give two main types of products on heating.

(1) Esterification of the alcoholic hydroxyl by the carboxyl of another molecule of the acid first gives hemilactide (XI) and then a lactide (XII) is formed.



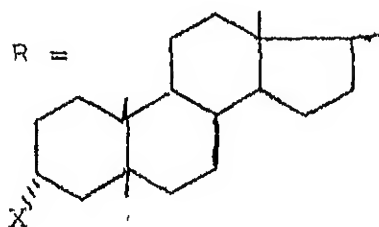
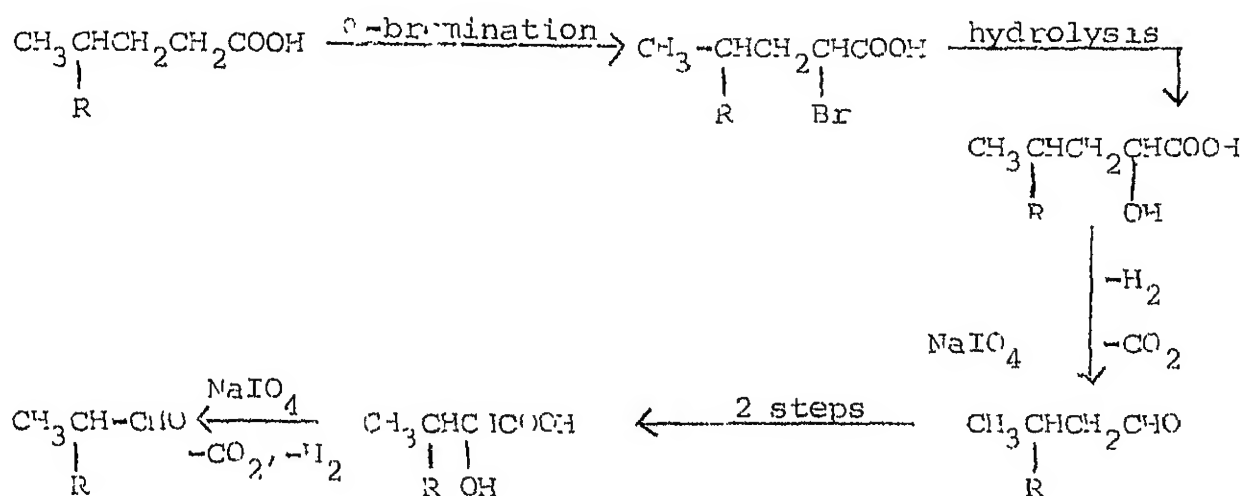
(2) Elimination of the elements of formic acid to yield an aldehyde



These reactions have been examined for acids upto α -hydroxy stearic acid. Hydroxy acids of the type $\text{RR}'\text{C}(\text{OH})\text{COOH}$ behave similarly on heating and yield ketones instead of aldehydes. In addition, unsaturated compounds are also formed.

Conversion of a carboxylic acid (or its derivative) to a carbonyl compound by the loss of one carbon atom plays an important role in Organic chemistry. This type of degradation is an important tool in the structure elucidation of natural products. Yehuda Yanuka³¹ have reported stepwise degradation of the side chain in bile acids by the use of SN_3Br , a carbon atom being eliminated each time as shown in Scheme III.6.

SCHEME III.6

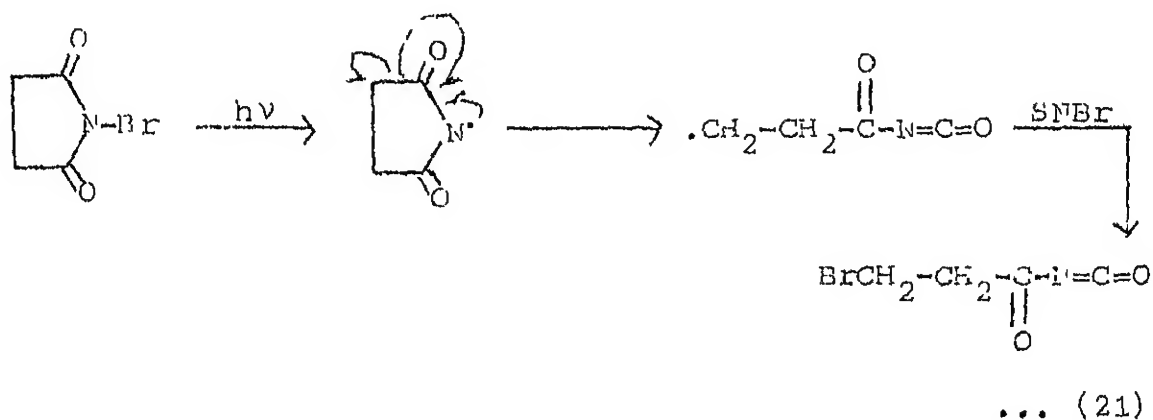


Chromic acid oxidation³² of mandelic acid yields benzaldehyde, benzoic acid and CO₂ in the ratio 1:1:2.

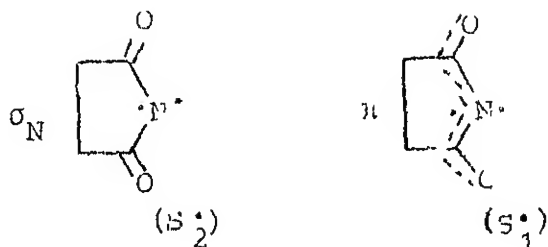
Reactive species most commonly encountered in SNBr reactions are succinimidyl radical, bromonium ion, bromine atom and molecular bromine. Though these species have been suggested in most of the SNBr reactions, the pathways for the formation of these species have not been formulated clearly.

Ever since the suggestion by Bloomfield in 1944 that succinimidyl radical can act as the chain carrying species in the allylic bromination of alkenes, this species has been invoked in

several SNBr reactions.^{33,34} For example, rearrangement of SNBr to β -bromopropionylisocyanate when SNBr is refluxed in CHCl_3 or CCl_4 in the presence of an olefin and a free radical initiator like benzoyl peroxide, or under irradiation has been suggested to proceed via the succinimidyl radical.³⁵ (Eqn.21)

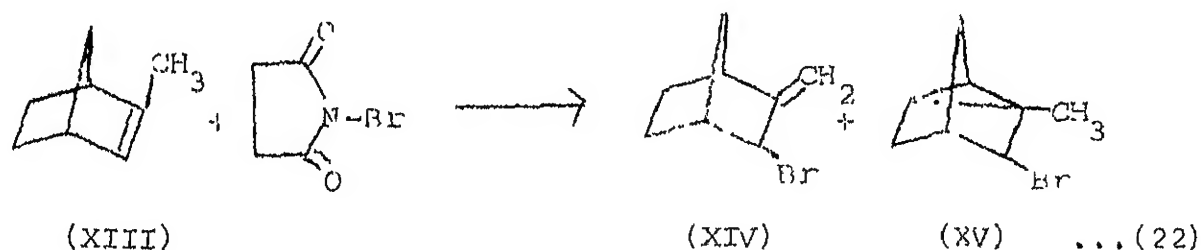


Skeell and Dey³⁶ have argued that the succinimidyl radical as formed in the above reaction has the odd electron in the σ orbital, designated as (S_2^\bullet), and is different from the one that is formed in the presence of bromine in which the odd electron is situated in the π orbital (S_1^\bullet). This conclusion is based on the fact that the latter radical does not undergo rearrangement to β -bromopropionyl isocyanate and also, the two species exhibit different reactivities in the competitive bromination of neopentane and methylene chloride using SNBr.

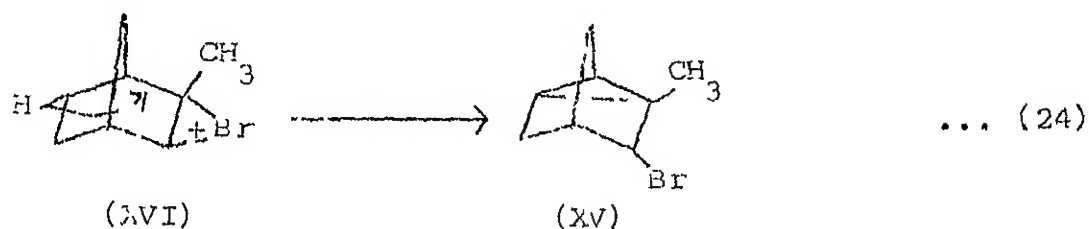
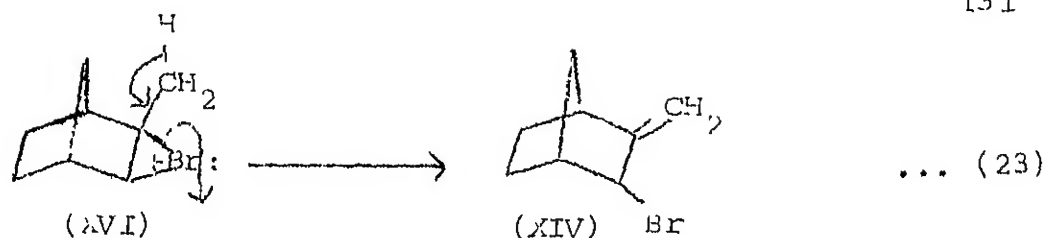


However, attempts to detect succinimidyl radical by the ESR spectroscopic method have failed³⁷ and strong evidence has been presented against the involvement of this reactive species in a large number of SNBr reactions. An example of such a reaction is the Wohl-Ziegler reaction.

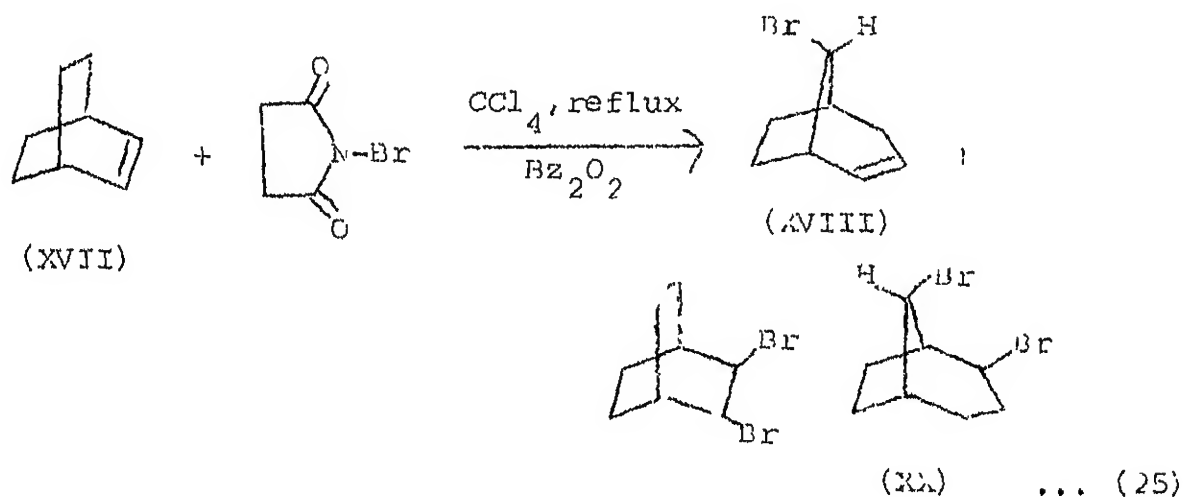
Benzylic bromination of toluenes proceeds by a free radical chain mechanism involving bromine atom as the hydrogen abstracting species. (c.f. Goldfinger mechanism).³⁹ Reaction of 3-methylnorborn-2-ene (XIII) with SNBr in CCl_4 in the presence of dibenzoylperoxide gave 3-bromo-2-methylene-norbornane (XIV) and 2-methyl-3-bromonortricyclane (XV) (Eqn.22).



Compound XV has been suggested to arise via an ionic mechanism (Eqn.24) and (XIV) via a free radical⁴⁰ mechanism, though both have earlier been postulated to arise from a common bromonium ion intermediate XVI.

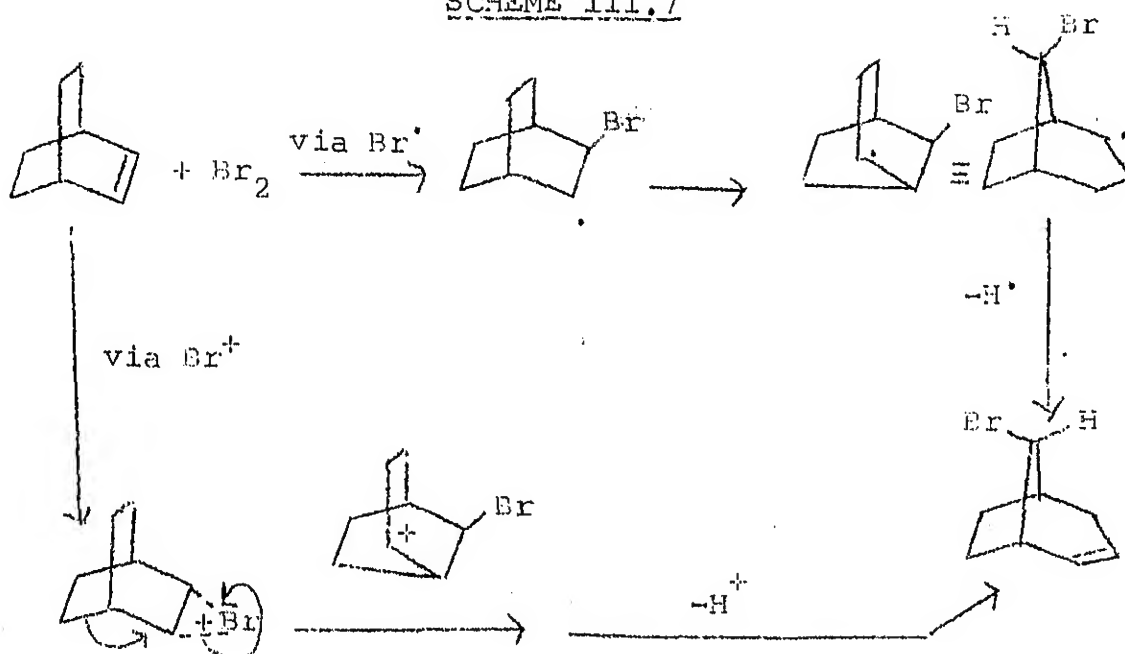


Similarly, both a free radical and an ionic mechanism has been suggested for the SNBr bromination of bicyclo[2.2.2]-oct-2-ene (XVII) which yielded endo-8-bromo-bicyclo-[3,2,1]-oct-2-ene (XVIII) along with the dibromides (XIX) and (XX)⁴¹ (Eqn.25).

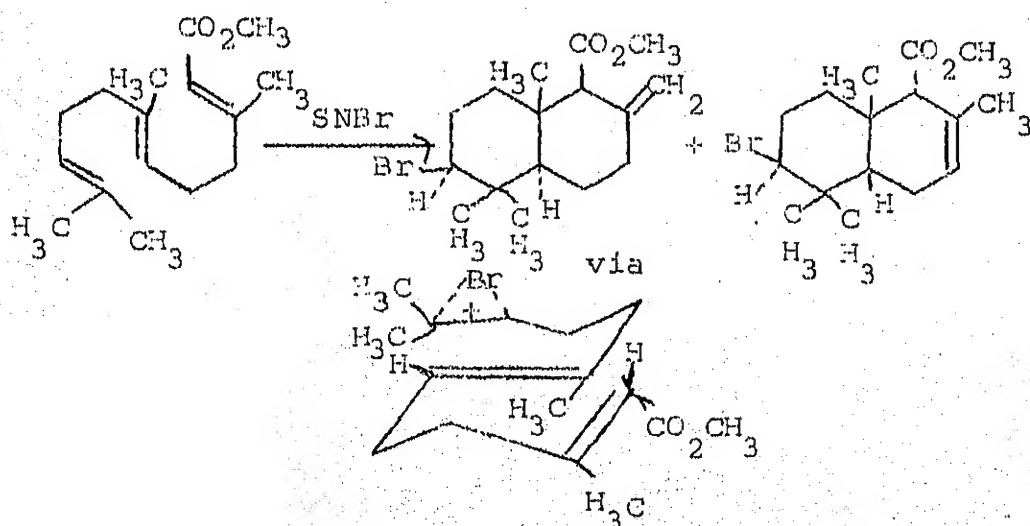


Stepwise formation of (XVIII) is as shown in Scheme III.7

SCHEME III.7

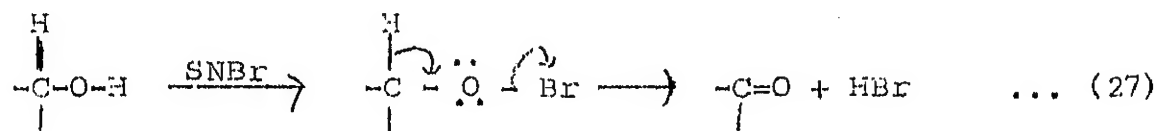


Cyclization of various terpenes on treatment with aqueous SNBr solution has been suggested to proceed via the initial formation of a terminal bromonium ion.⁴² (eqn. 26)

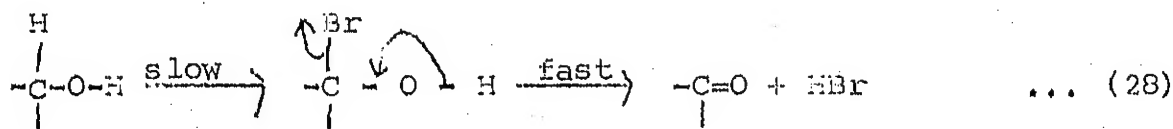


Oxidation of alcohols to aldehydes and ketones can be effected by both SNBr and Br_2 , and since Br_2 is formed during the reaction of SNBr with alcohols, it has been suggested that Br_2 is the oxidizing agent in the SNBr oxidation of alcohols.⁴³

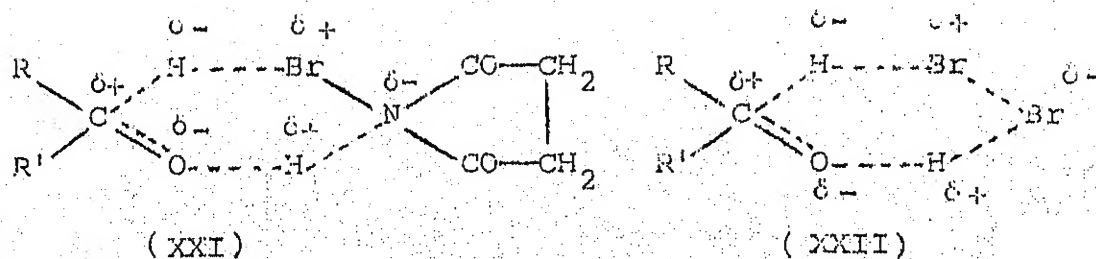
Krause and coworkers⁴⁴ tentatively suggested that the SNBr oxidation of alcohols may proceed through an alkyl hypobromite intermediate (Eqn.27).



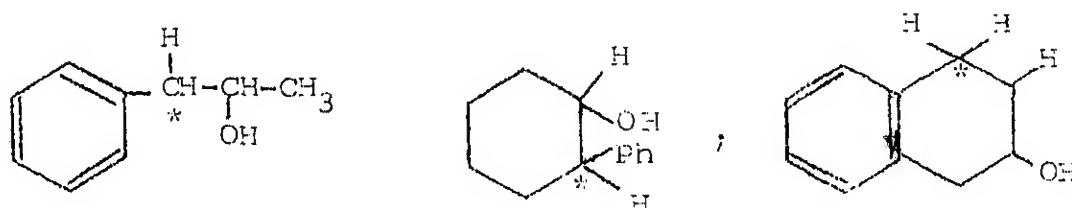
Lecomite and Gault⁵¹ have on the other hand, suggested that halogen substitution on the OH-bearing carbon atom follows a rapid dehydrobromination (Eqn.28).



Thiagarajan and Venkatasubramanian^{43(a)} have proposed a cyclic transition state XXI for SNBr oxidation of alcohols on an analogy drawn from the suggested transition state (XXII) for Br_2 oxidation involving the breaking of C-H bond as a hydride anion.

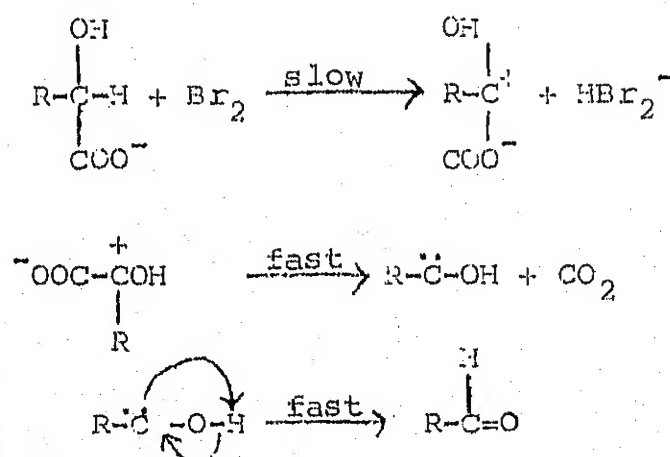


The SNBr oxidation⁴⁵ of 1-phenyl propan-2-ol, trans-2-phenyl cyclohexanol and β -tetralol proceeds through the bromination at the benzylic carbon atoms shown below:



Kalyan K. Banerjee⁴⁶ has suggested molecular bromine to be the active oxidising species in the oxidation of α -hydroxy carboxylic acids with bromine (Scheme III.8).

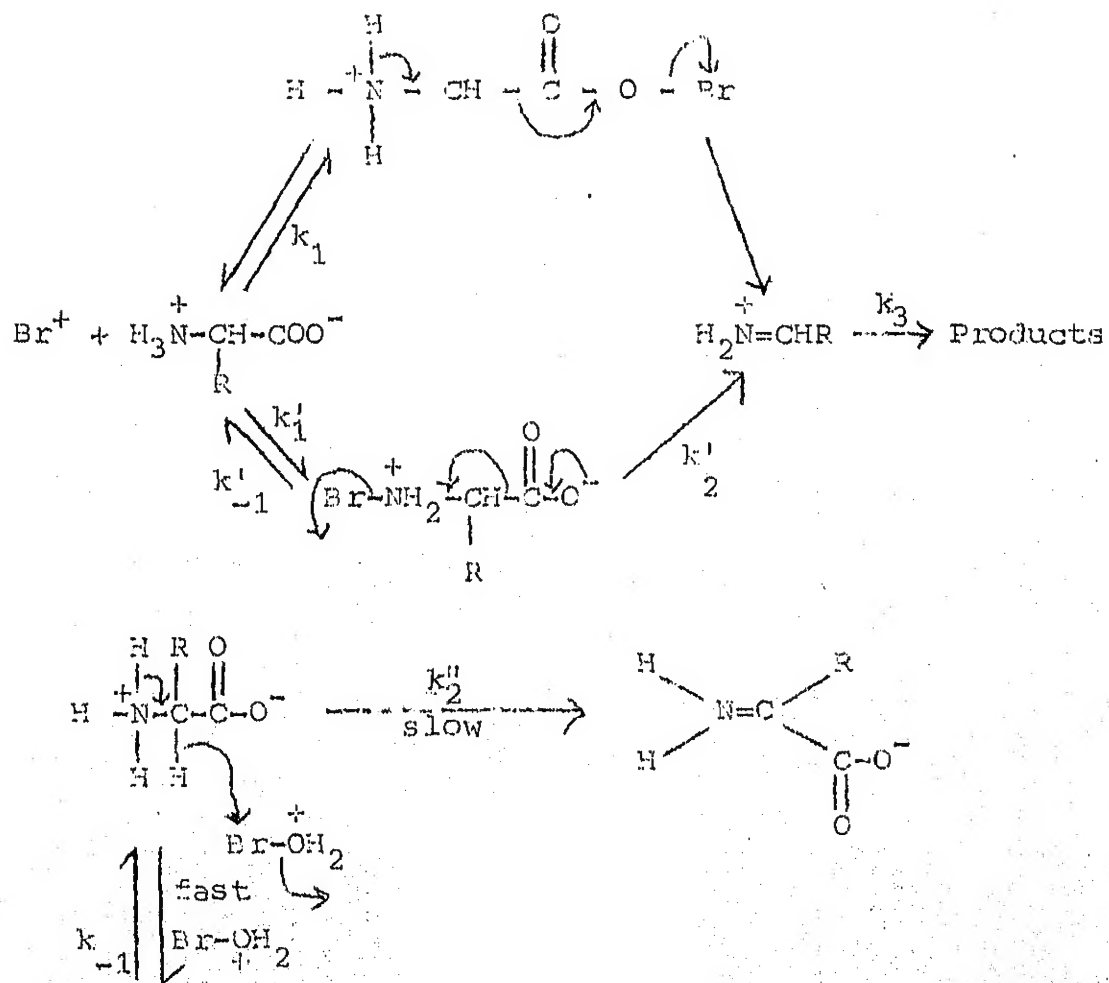
SCHEME III.8



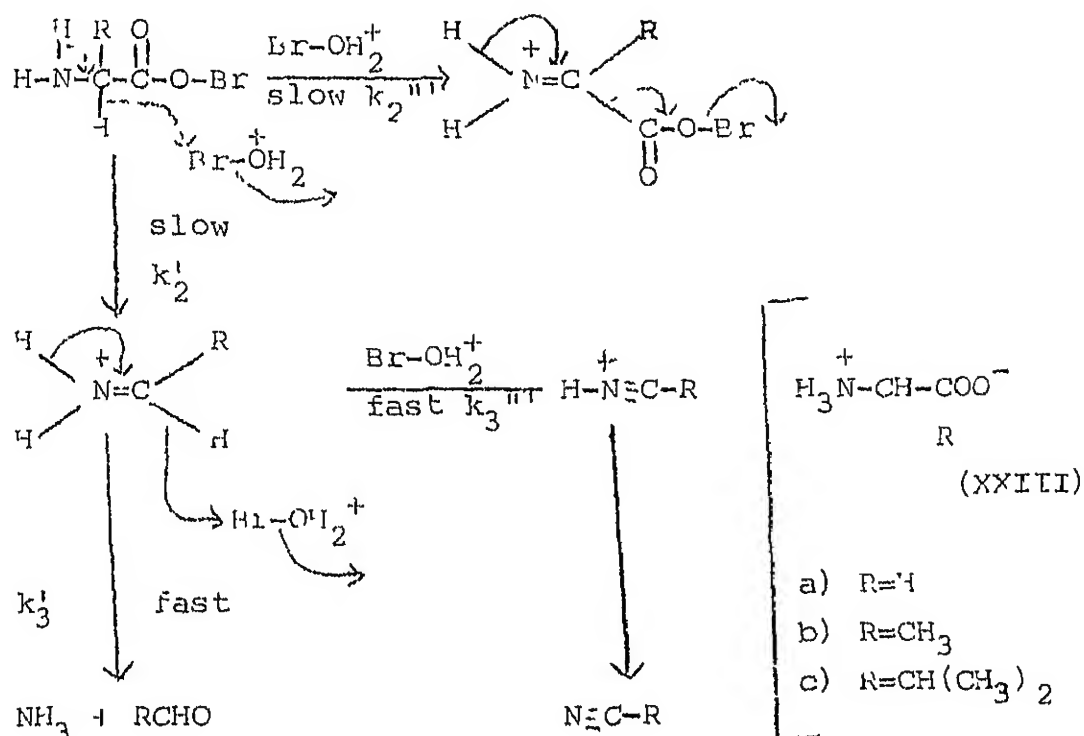
The mechanism of oxidative decarboxylation⁴⁷ of glycine (XXIIIa), DL-alanine (XXIIIb) and DL-valine (XXIIIc) promoted by SNBr has been shown to involve the formation of an acyl

hypobromite of (XXIIIa); its slow decomposition to an imine and subsequent rapid conversion of imine to products. (XXIIIb) and XXIIIc undergo oxidation by a mechanism involving the slow abstraction of the α -hydrogen in the form of hydride ion from the substrate as well as its acyl hypobromite to give imine (Scheme III.9).

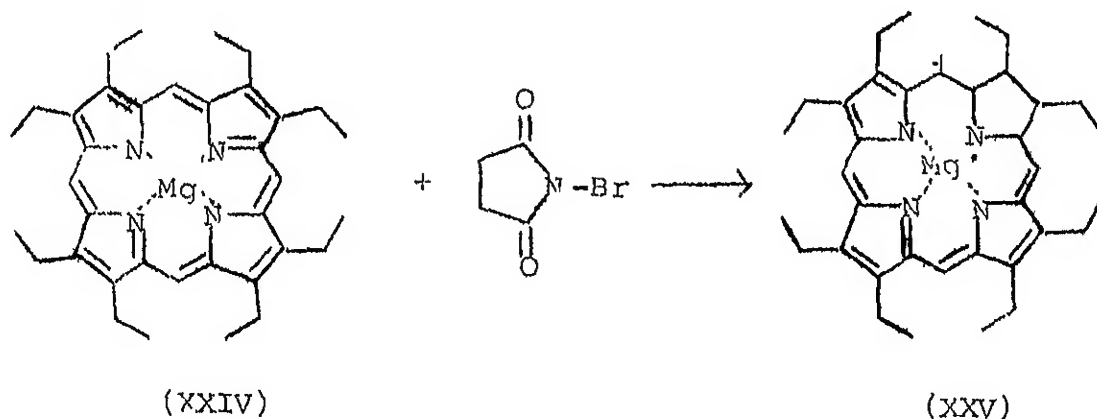
SCHEME III.9



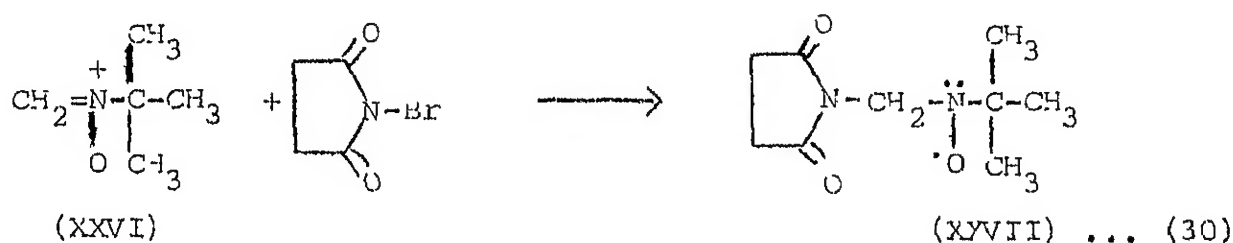
Scheme III.9 (contd.)



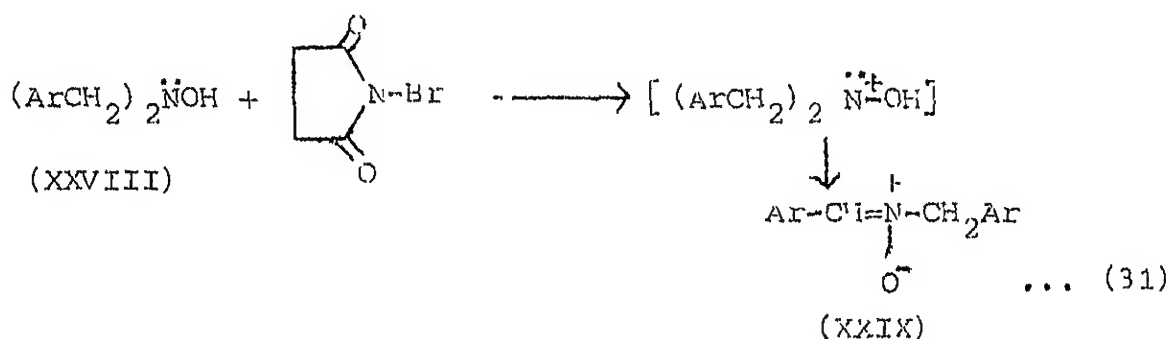
The mechanism of oxidative decarboxylation of amino acids promoted by $\text{S}_\text{N}\text{Br}$ has been shown to be significantly influenced by the presence of alkyl groups at the α -carbon. Magnesium octaethylporphyrin (XXIV) has been found to be oxidised by $\text{S}_\text{N}\text{Br}$ giving the corresponding radical cation (XXV) via one-electron oxidation process⁴⁸ (Eqn.29).



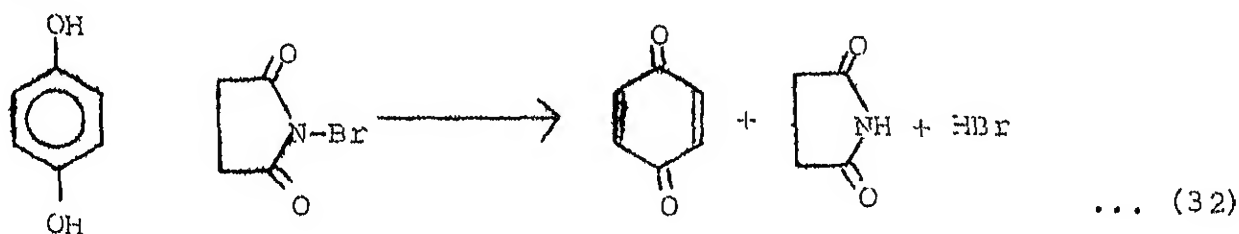
Methylene t-butyl nitron (XXVI) has been found to react with SNBr giving, nitroxide radical (XYVII) as shown in (Eqn.30) the presence of which was established by ESR spectroscopy method.⁴⁹

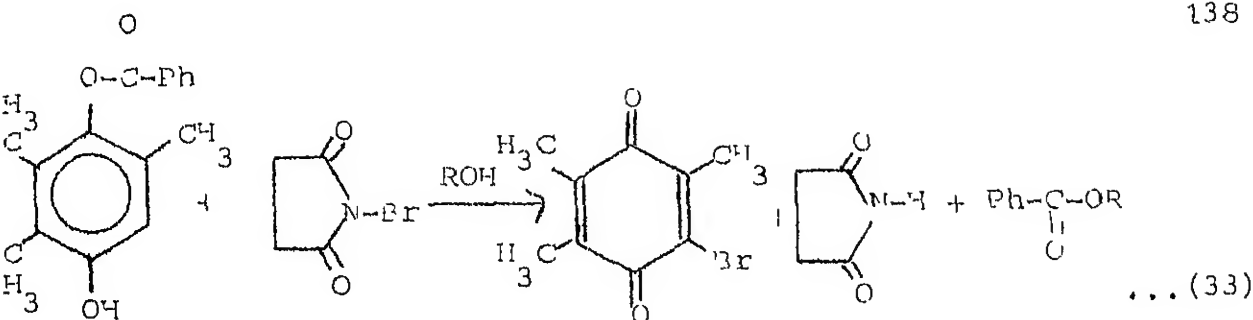


Similarly, the oxidation of diarylmethyl-hydroxylamines (XXVIII) by SNBr has been reported to give nitrones (XXIX) via initial one-electron oxidation of the substrate by SNBr (Eqn.31).

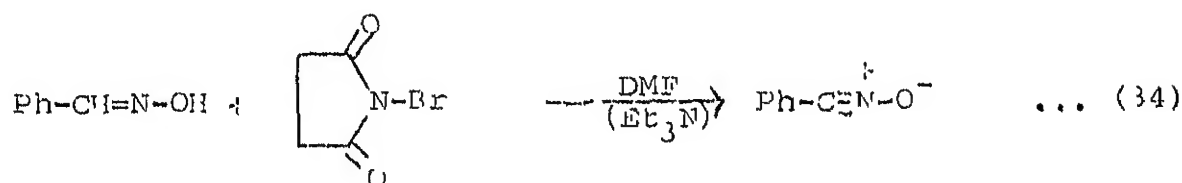


Oxidation of hydroquinones by SNBr gives corresponding quinones (Eqn.32); aromatic hydroxy esters give corresponding quinones,⁵⁰ with bromine at the unsubstituted nuclear position (Eqn.33).





Oxidation of aldehyde oximes with SNBr in DMF referred to vide Eqn.16 earlier gives nitrile oxides (Eqn.34).



The mechanism of oxidation has been shown to involve an ionic process. The reaction proceeds by substitution of the hydrogen on the carbon bearing the hydroxyl group followed by rapid loss of hydrogen bromide.⁵¹ The rate determining step is the cleavage of the -C-H bond.

The 7α -hydroxyl group in cholic acid was oxidized to the carbonyl group (while the 3α - and 12α -hydroxyl groups were unaffected by SNBr in aqueous sodium bicarbonate,⁵² (or aqueous acetone or dioxan⁵³) and the carbonyl group could then be reduced to give desoxycholic acid. All three hydroxylic functions mentioned above are, however, oxidised using SNBr in tert. butyl alcohol.⁵³ Cholestane- $5\alpha, 6\beta$ -diol has been oxidised to 5α -hydroxycholestan-6-one⁵⁴ and only the 6β -hydroxyl group was oxidised when cholestane- $3\beta, 5\alpha, 6\beta$ -triol was treated with SNBr .⁵⁵

The selective oxidation by SNBr of a variety of hydroxylic groups in steroidal alcohols has been studied by Kawanami⁵⁶ who concluded that the most significant factor in the oxidation of the less active equatorial alcohols was the approach of the base to the axial-C-H bond of the carbon atom whose hydroxyl group was being oxidised.

Simple primary and secondary alcohols are oxidised to appropriate carbonyl compounds, generally isolated as the 2,4-dinitrophenyl hydrazones.⁵⁷ The use of N -haloimides for the dehydrogenation of primary and secondary alcohols to aldehydes and ketones was studied by Grob and Schmid.⁵⁸ The oxidation of polyvinyl alcohol with SNBr has been reported to affect conversion of approximately 2-6 percent of the hydroxyl groups to the carbonyl groups.⁵⁹

SNBr has also been used as an oxidant for the conversion of aromatic keto alcohols and secondary alcohols to the corresponding carbonyl compounds.^{60,61}

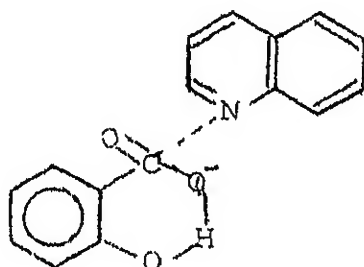
Results of studies by Franke and Bratnun,⁶² and by Locke,⁶³ on the decarboxylation of dihydromaleic acid indicate that the monoanion at 40° in water suffers decarboxylation 40 times faster than the undissociated acid.

Brown, Hammick and Scholefield⁶⁴ studied the decarboxylation of several hydroxybenzoic acids in resorcinol and proposed a bimolecular mechanism for the reaction. Clark studied the

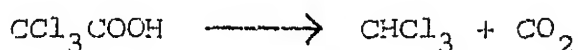
decarboxylation of 2,4-dihydroxybenzoic acid in amines, glycols,⁶⁵ phenols and acids.⁶⁶ His results show that at 100°, the rate constant for the decarboxylation of 2,4-dihydroxybenzoic acid is 65 times greater in quinoline than it is in octanoic acid.

These results suggest that 2,4-dihydroxybenzoic acid ionizes in quinoline and the anion suffers decarboxylation, whereas in octanoic acid, ionization is repressed and the undissociated molecule decomposes. The supposition that the anion is involved in the decarboxylation of 2,4-dihydroxybenzoic acid in quinoline is supported by the fact that the enthalpy of activation of the reaction in quinoline is higher than it is in the acid solvent and was noted in the parallel cases of oxalic and oxamic acids. The fact that the anions of β -hydroxy acids appear to be more unstable than the undissociated acids, in contrast to the behavior of α - and β -keto acids may be a result of the greater hydrogen-bonding potential of the hydroxyl group as opposed to the keto group.

The mechanism of the decarboxylation of α - and β -hydroxy acids and their anions is quite similar to the decarboxylation of α - and β -keto acids and their anions. The rate determining step in the decarboxylation of the hydroxy acids is the formation of an activated complex shown below:

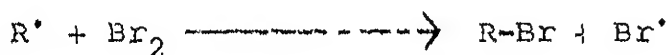
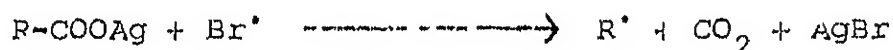
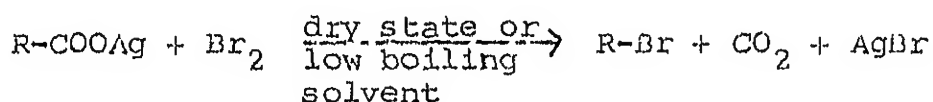


In 1884, Silberstein observed that trichloroacetic acid is split quantitatively into chloroform and CO_2 when heated in organic bases such as aniline, *N,N*-dimethyl aniline, quinoline and pyridine.

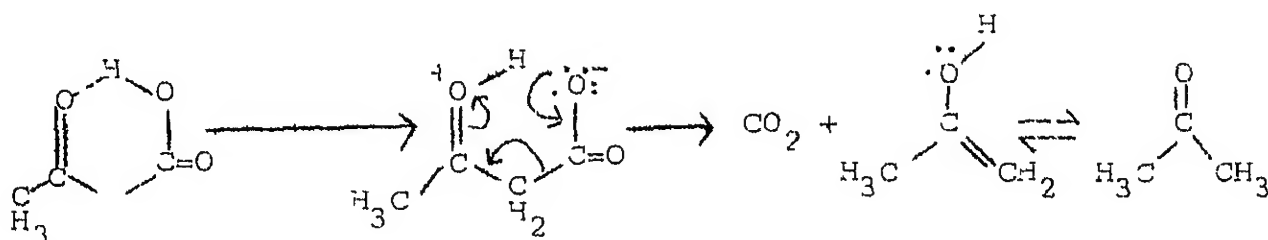


In the decarboxylation of the unionized as well as the ionized forms of acids, the mechanism is believed to involve the formation of an activated complex by way of a nucleophilic bimolecular addition reaction, followed by the loss of carbon-dioxide by heterolytic cleavage. The rate-determining step in every case appears to be the formation of an activated complex via a nucleophilic attack on a π -bonded carbon atom.

An example of free radical decarboxylation was encountered in Kolbe hydrocarbon synthesis and Hunsdiecker reaction where silver salt of a carboxylic acid reacts with bromine to lose CO_2 yielding an alkyl bromide.



One of the mechanisms put forth for the decarboxylation of β -keto carboxylic acids is as follows:



The above survey of the literature reveals the possible significance of the reactions of SNBr with hydroxy and carboxyl groups present in separate molecules constituting different chemical and biological systems also indicates that though much has been gathered on the reactions of SNBr, a lot still remains unexplored. Reactions of SNBr offer challenging opportunities for mechanistic investigations. In view of this, we decided to study a few reactions of N-bromosuccinimide with a few α -hydroxy carboxylic acids which contain both-hydroxy and carboxyl groups in the same molecule.

III.3 Results and Discussion

From the facts presented in the previous section it is evident that N-bromosuccinimide (SNBr) acts as an oxidising agent in its reactions with a variety of substrates including carboxylic acids and alcohols; but the mechanistic pathways for such oxidations

are obscure. In order to examine the mechanistic details, reactions of N-bromosuccinimide with a few α -hydroxy carboxylic acids and their salts have been examined under different conditions. It is known that the α -hydroxy carboxylic acid viz glycolic acid, mandelic acid and benzilic acid as well as their salts are stable in refluxing dimethylformamide; but carbon dioxide evolution takes place when these acids or their salts are refluxed along with N-bromosuccinimide in DMF medium. These observations have also been made in the present study which along with additional data recorded by us are listed in Table III.1.

Table III.1. Reactions of 0.005 mol of α -hydroxy acids^a

$$\begin{array}{c} \text{RR}'\text{C} - \text{C}(\text{OH}) \\ | \quad \quad || \\ \text{OH} \quad \text{O} \end{array}$$
 or their sodium/potassium salts with
 N-bromosuccinimide in dry DMF medium at reflux
 temperature under nitrogen atmosphere for 1 h
 unless otherwise specified.

Run.	Substrate acid or salt (0.005mol)	N-Bromo- succinimide (mol)	% Yields of products				%Star- ting material (as acid) reco- vered
			R-CO-R'	R'RCHOH	CO ₂	Succi- nimide	
1	2	3	4	5	6	7	8
1.	Acid(R=R'=H)	0.01	45	5	53	46	44
2.	Acid(R=R'=C ₆ H ₅)	0.01	69	-	70	68	28
3.	K salt(R=R'=H)	0.005	8	35	48	66	46

Table III.1(contd.)

Table III.1(contd.)

1	2	3	4	5	6	7	8
4.	K salt($R=R'=H$)	0.01	55	21	76	79	12
5 ^b .	Na salt($R=H, R'=C_6H_5$)	0.005	13	26	49	62	45
6.	Na salt($R=H, R'=C_6H_5$)	0.01	65	6	85	83	10
7 ^b .	K salt($R=R'=C_6H_5$)	0.005	18	19	47	60	44
8.	- do -	0.01	79	-	88	86	10
9.	- do -	0.005	45	-	45	48	45
10. ^d	- do -	0.005	6	8	12	46	81
11. ^e	- do -	0.01	87	-	89	90	-
12. ^f	- do -	0.01	no reaction				
13. ^g	K salt($R=R'=H$)	0.01	18	56	78	80	13
14. ^g	- do -	0.005	-	41	48	46	46

a. α -Hydroxy acids used were glycolic acid ($R=R'=H$), mandelic acid ($R=H, R'=C_6H_5$) and benzillic acid ($R=R'=C_6H_5$).

b. Presence in small quantities of $C_6H_5CH(OH)-CH(OH)C_6H_5$ in run 5 and $(C_6H_5)_2C(OH)-C(OH)(C_6H_5)_2$ in run 7 was also detected.

c. In oxygen atmosphere.

d. In the presence of 150-W bulb kept one ft. away from the reaction flask and under stirring for 12 h.

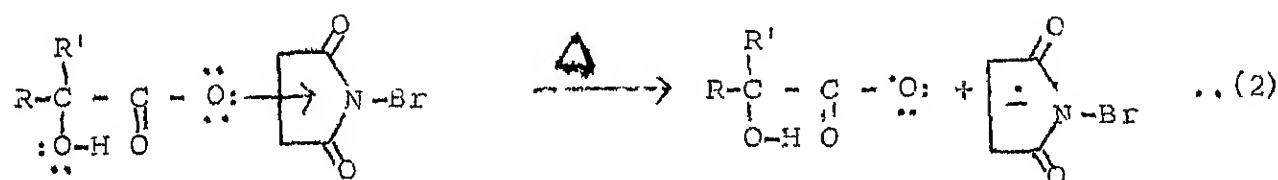
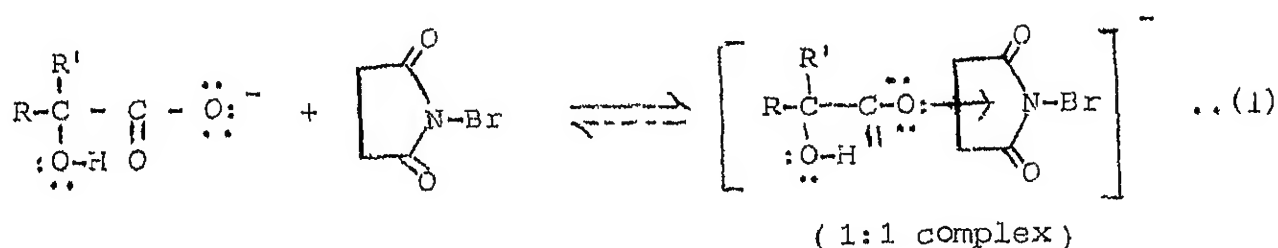
e. Reaction time increased to 6 h.

f. Under stirring at room temperature for 12 h.

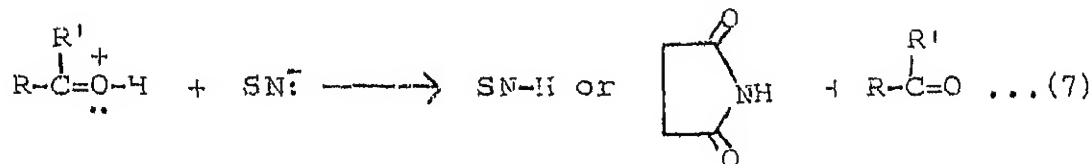
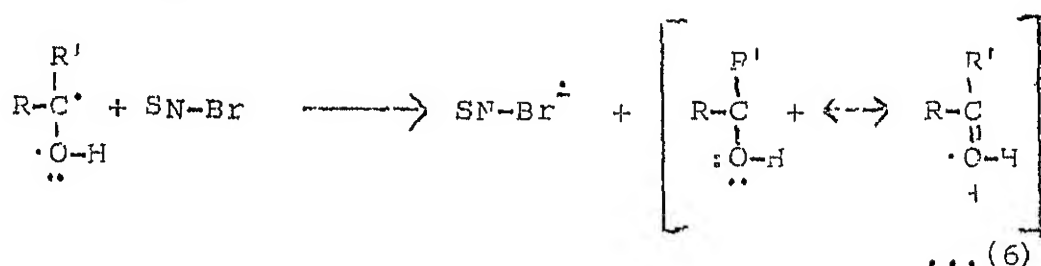
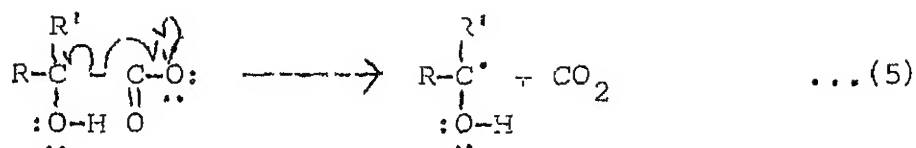
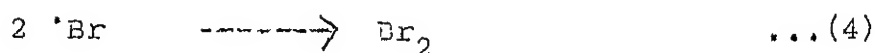
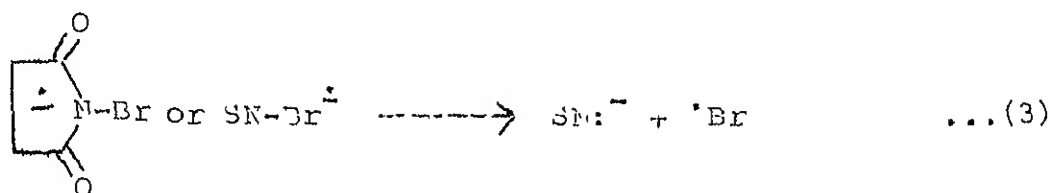
g. In the presence of 0.01 mol. cumene.

It is evident from these data that the reactions conducted with 1:1 molar ratio of the two reactants generally went forward to the extent of about 50%; while those involving double the quantity of N-bromosuccinimide were nearly complete in 1 h. at the reflux temperature in DMF medium. It is noteworthy in this connection that at room temperature, potassium salt of benzoic acid did not produce any reaction with N-bromosuccinimide under otherwise similar conditions (run 12). In view of the fact that N-bromosuccinimide can act as a single electron acceptor a new electron transfer mechanism for the reactions of the salts of α -hydroxy carboxylic acids with N-bromosuccinimide in 1:2 molar ratio is proposed in Scheme III.10 which rationalizes all other observations also quite satisfactorily.

SCHEME III.10



Scheme III.10(contd.)

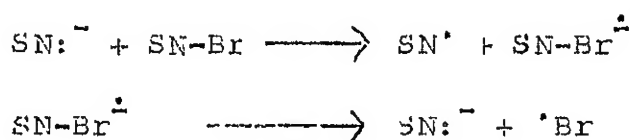


The reversible formation of 1:1 charge transfer complex in step 1 is followed by its thermal decomposition resulting in an electron transfer from the carboxylate anion to SNBr. The radical anion of the SNBr formed in step 2 undergoes cleavage at the N-Br bond giving succinimidyl anion and bromine atom (step 3). The greater electronegativity of nitrogen compared to that of bromine

would prevent this cleavage from going in the direction of succinimidyl radical and bromide anion formation. The coupling of two bromine atoms gives molecular bromine (step 4) which has been actually found to be present in all the reactions. The radical corresponding to the carboxylic acid anion obtained in step 2 by the loss of one electron from the latter undergoes a C-C bond homolysis producing carbon dioxide gas and an hydroxy alkyl carbon radical as in step 5. A part of these carbon radicals may abstract hydrogen atoms from the DMF giving alcohols such as methanol and benzyl alcohol according to step 9, while rest of the carbon radicals are further oxidized by the unreacted S_NBr present, giving protonated carbonyl compounds as shown in step 6. On the removal of a proton from the latter with the help of succinimidyl anion, carbonyl compounds such as formaldehyde, benzaldehyde and benzophenone are produced as in step 7. Non-existence of benzylidene alcohol among the products in run 8 may be attributed to the greater resonance stability of benzhydryl radicals towards hydrogen abstraction from DMF. The formation of alcohol by means of hydrogen abstraction by the carbon radicals from the medium is confirmed from the observations recorded for run 13 wherein in the presence of efficient hydrogen atom donor more methyl alcohol is produced at the expense of formaldehyde (compared to run 4).

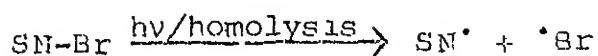
From the results obtained on the reactions using salts of α -hydroxy carboxylic acid and S_NBr in 1:1 molar ratio it is also

clear that N-bromosuccinimide oxidizes the carbon radicals to the corresponding protonated carbonyl compounds (step 6) faster than it oxidizes the carboxylate anion to the corresponding radical (steps 1 & 2). Hence close to 50% of the starting carboxylate anion is recovered unreacted at the end of the reaction in the form of α -hydroxy acid. The succinimidyl anion produced in the reaction may also reduce the SNBr present in excess as follows

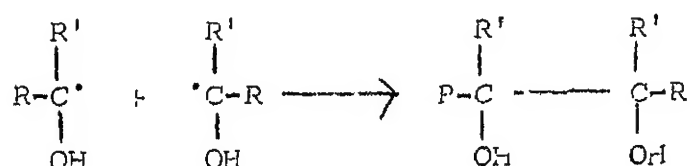


Recovery of larger quantities of unreacted α -hydroxy acids in runs 1 and 2 compared to the recoveries made in runs 4 and 6, respectively also confirms that the SNBr oxidation of the salts of α -hydroxy carboxylic acids occurs faster compared to the oxidation of α -hydroxy carboxylic acids themselves. In the reactions involving acids (not their salts) the formation of 1:1 complex between the two reactants corresponding to step 1 appears to be slower. That the equilibrium of the type illustrated in step 1 may be quite significant is demonstrated by the results obtained in run 11 (compared to run 8) where increasing the reaction time lead to the full consumption of the starting carboxylic acid salt. In run 10 which was carried out under photochemical conditions, the oxidising reagent, SNBr preferentially underwent homolysis of the N-Br bond resulting the destruction of the oxidant.

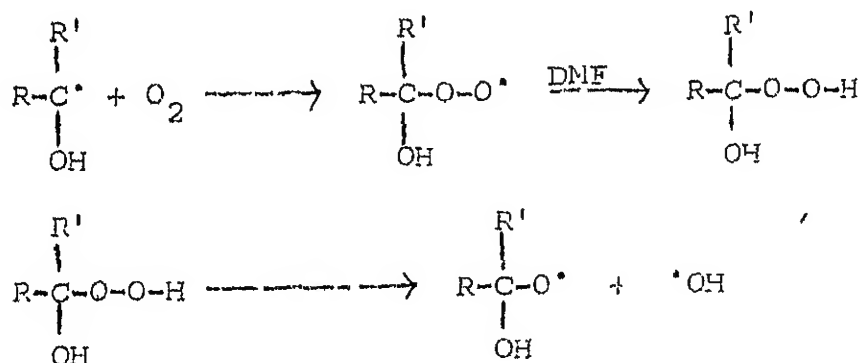
Thus, very little oxidation of the carboxyl anion took place.

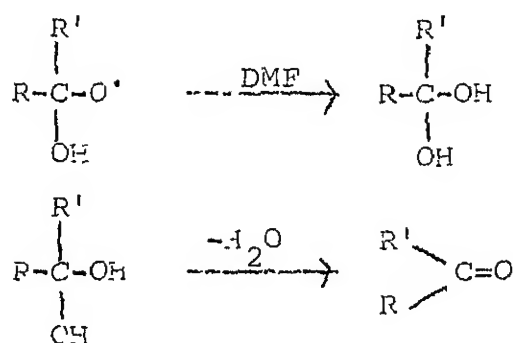


The presence of carbon radicals as produced in step 5 is also confirmed from runs 5 and 7 wherein small quantities of pinacols presumably formed by the radical dimerisation illustrated below were found among the products.



A comparison of the results obtained in run 9 (conducted in the presence of O_2) with those obtained in run 7 indicates the trapping of carbon radicals with molecular oxygen and subsequent formation of benzophenone at the expense of benzhydryl alcohol and benzpinacol, $(\text{C}_6\text{H}_5)_2\text{C}(\text{OH})-\text{C}(\text{OH})(\text{C}_6\text{H}_5)_2$.

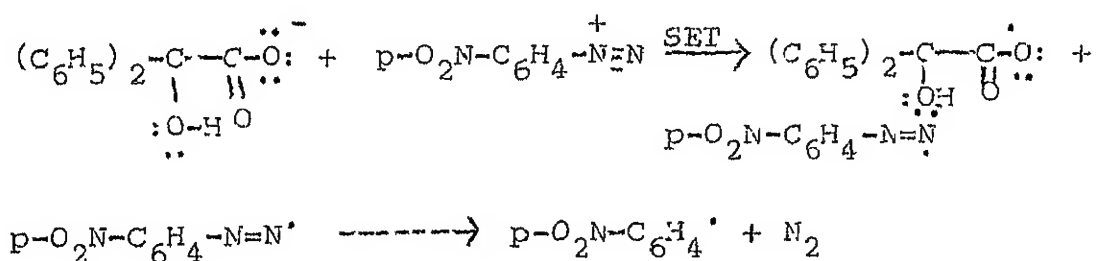




Succinimide being highly soluble in water could not be fully recovered from the reaction mixture.

The arguments advanced in support of the new mechanism proposed in Scheme III.10 above are further substantiated by our results obtained as recorded under experiments 15 and 16 in the Experimental Section III.4. Thus, the use of p-nitrobenzenediazonium cation as an oxidising reagent instead of N-bromosuccinimide for the oxidation of benzoic acid anion gave the results which can be accounted for by the electron transfer mechanism outlined in Scheme III.11.

SCHEME III.11



Scheme III.11(contd.)

chromatography and determination of melting point and mixed melting points. Literature melting points are cited from "Handbook of Chemistry and Physics" 50th edition, R.C. Weast (Ed.) published by Chemical Rubber Co., Cleaveland, Ohio, unless otherwise specified.

Starting materials:

Potassium salts of glycolic and benzoic acids and sodium salt of mandelic acid were prepared by known procedures. N-Bromo-succinimide (NBr) was recrystallised from hot water before use. Dimedone (BDH) was used without further purification. Cumene (Koch-light) was used after distillation. Deaerated dry DMF was prepared as summarised below:

Preparation of deaerated dry N,N-Dimethyl formamide (DMF)

DMF was kept over calcium chloride (fused) for 24 h, after which it was decanted into a 1 l round bottomed flask. The liquid was distilled at atmospheric pressure and, the fraction distilling over a temperature range 152-154°C was collected. DMF was deaerated by passing pure, dry nitrogen continuously for 1 h, into the solvent contained in a 1 l. round bottomed flask mounted over a magnetic stirring base.

Estimation of formaldehyde and benzaldehyde

To a 50 ml portion of solution taken out from the solution meant for aldehyde estimation in specific experiments, an aqueous

saturated solution of dimedone (50 ml) was added. After stirring for 6 h. over a magnetic stirring base, the mixture was allowed to stand for 40 h. The precipitated dimedone derivative of the aldehyde was separated by filtration and dried at 60°C . It was characterised by mixed melting point and its superimposable IR spectrum with that of an authentic sample. The total yield of the dimedone derivative and hence that of the aldehyde in the entire solution used as aldehyde trap was subsequently extrapolated.

Estimation of CO_2 gas:

The gas evolved in the reaction was passed into a CO_2 absorption device consisting of a stoppered conical flask containing 75 ml of an aqueous solution of $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ prepared by dissolving 7.88g; 0.025 mol of $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ in distilled water, placed over a magnetic stirring base. The baryta solution was stirred continuously while the gas evolved was allowed to pass into it turning the solution turbid. After the evolution of gas ceased, the contents of the conical flask were carefully transferred into a 100 ml measuring flask. After rinsing the flask twice with about 10 ml portions of distilled water and pouring the washings into the measuring flask, the volume of the solution in the measuring flask was made up to 100 ml by adding distilled water.

A 20 ml portion of this solution was pipetted out into a clean conical flask and the unreacted barium hydroxide titrated against standard hydrochloric acid using phenolphthalein as indicator. The titration was repeated a few times to get a constant reading for the volume of the standard acid required.

The volume of standard alkali which reacted with the CO_2 was then computed. The total percentage of carbondioxide evolved was thus determined.

Detection of Br_2 gas:

To a 50 ml portion of the solution obtained after pouring the reaction mixture into acidified (HCl) water, 5 g of potassium iodide was added. Due to formation of I_2 , a violet coloration appeared. This was followed by the addition of sodium thiosulfate till the color of iodine disappeared. The presence of molecular bromine which oxidized the iodide to I_2 , was observed in all the reactions excepting run 12.

1. Reaction of glycolic acid (0.005 mol, 0.38g) with SNBr (0.01 mol, 1.78g) under nitrogen atmosphere in dry DMF at reflux temperature

Glycolic acid (0.38g) and dry DMF (30 ml) were placed in a 3-necked RB flask mounted over a magnetic stirring base. The open end of the condenser fixed to the RB flask was connected to a conical flask containing 100 ml of acidified (HCl) aqueous methanol

(1:1 by vol) used as a trap for formaldehyde, which was connected, in turn, to another conical flask containing 75 ml of standard $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ solution serving as trap for CO_2 . After flushing the contents of the system with dry N_2 gas for 10 min, the contents of the RB flask were heated over an oil-bath maintained at a temperature range $70-80^\circ$. SNBr (1.78g; 0.01 mol) in 30 ml dry DMF was then added to the RB flask. Evolution of CH_2O and CO_2 gases started after 5 min. of heating and got absorbed in the respective conical flasks serving as traps. Gas evolution stopped after 25 min. The contents of the RB flask were then heated for additional 30 min. with stirring. Thereafter, the contents of the RB flask were cooled to room temperature and poured 200 ml of acidified (HCl) ice-cold water giving a solution labelled as solution A_1 .

The contents of the conical flask which trapped formaldehyde were used for the determination of formaldehyde as described earlier. The yield of formaldehyde formed was estimated to be 45%, characterised by the melting point and mixed melting point of the dimedone derivative. Mp, 187° (found); lit m.p., 189°C .

A 50 ml portion of solution A_1 was used for detection of Br_2 as mentioned above.

To the rest of the solution A_1 , solid NaOH flakes were added to make it just alkaline. NaCl (10g) was then added and the mixture extracted with ether. The ethereal layer was separated, washed with water and dried over anhydrous Na_2SO_4 . The extract

was then concentrated by evaporation of the ether. GLC analysis of the concentrated ethereal extract indicated the presence of methanol 5% in the entire solution A_1 (by comparison with an authentic sample).

The aqueous layer was, thereafter, extracted with dichloromethane. After drying the extract the solvent was removed when crystals of succinimide were obtained. The compound was identified by IR and melting point methods. Total yield of succinimide contained in solution A_1 was found to be 0.82g (46%); m.p. 260° ; lit.m.p., 260° .

The aqueous layer remaining after extraction with CH_2Cl_2 was then acidified with HCl and extracted with ether. The ethereal layer was washed and dried. Evaporation of ether yielded the starting glycolic acid, characterised by melting point and mixed melting point technique. Total yield of this acid in solution A_1 was estimated to be 0.17g (44%).

The amount of CO_2 evolved estimated using the contents of the conical flask used as CH_2O trap as described earlier was found to be 53%.

2. Reaction of benzoic acid (0.005 mol; 1.240g) with SnBr_4 (0.01 mol, 1.78g) in dry DMF (30 ml) under nitrogen atmosphere at reflux temperature

In a 3-necked RB flask mounted over a magnetic stirring base, benzoic acid (1.24g, 0.005 mol) was placed and 30 ml of

dry DMF added. One neck of the RB flask was connected to a gas passing adapter to pass pure dry N_2 , to the other neck was attached a condenser whose open end was connected to a conical flask containing standard barium hydroxide solution (75 ml) serving as CO_2 trap. To the third neck of the RB flask was attached a dropping funnel containing 1.78g, 0.01 mol of $SNBr$ in 30 ml dry DMF. After flushing the flask with nitrogen gas for 10 min, the contents of the flask were heated in an oil bath maintained at a temperature ranging from 70° to 80° and $SNBr$ solution added. The gas formed as the reaction occurred was allowed to be absorbed in the CO_2 trap. Evolution of gas which commenced after 5 min. of heating stopped within 25 min. The contents of the flask were further heated for 30 min. and later cooled to room temperature and then poured into 200 ml acidified (HCl) ice cooled water.

On addition of the reaction mixture to acidified water, a white precipitate was formed which was separated by filtration (filtrate labelled as solution A_2) and found to be benzophenone (0.86g; 69% yield). The ketone was characterised by the preparation of 2:4-dinitrophenyl hydrazone derivative, melting point and mixed melting point technique. Mp. of 2:4 DNP derivative 239° (found) lit. mp., 240° (Dictionary of organic compounds). Mp of benzophenone 45° (found). A 50 ml portion of solution. A_2 was used for detection of Br_2 as usual.

The remaining solution A_2 was made just alkaline by the addition of sufficient quantity of NaOH flakes and thereafter 10g of NaCl was dissolved in it. Extraction of this aqueous solution with dichloromethane, washing with water, drying over $MgSO_4$ gave a solution, evaporation of the solvent (CH_2Cl_2) from which yielded succinimide characterised by comparison of its IR spectrum with that of an authentic sample and determination of its melting point. Mp. -260° (found); lit -260° . The total estimated yield of succinimide as contained in solution A_2 was estimated to be 1.21g; 68%.

The above aqueous solution A_2 left after extraction with dichloromethane was just acidified to precipitate the starting acid, (benzilic acid). The precipitate was filtered, washed, dried and weighed to give benzilic acid. Mp. 150° (found), lit. m.p., 150° . Total estimated quantity in solution A_2 was 0.35g; 28%.

CO_2 (70%) was found to have evolved in this reaction as estimated by the procedure described earlier.

3. Reaction of potassium salt of glycolic acid (0.005 mol; 0.57g) with SNBr (0.005 mol; 0.89g) in dry DMF under nitrogen atmosphere at reflux temperature.

In a 3-necked RB flask, mounted over a magnetic stirring base, fitted with a device to pass pure dry N_2 , condenser connected to a conical flask containing acidified (HCl) aqueous methanol

(1:1 by vol) serving as CH_2O trap which was connected in turn to a conical flask containing 75 ml of standard $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ solution to serve as CO_2 trap was placed 0.57g (0.005 mol) of potassium salt of glycolic acid in 30 ml dry DMF. Pure dry N_2 was passed into the flask for 10 min after which it was placed in an oil-bath maintained at a temperature ranging from 70° to 80° and 0.89g (0.005 mol) of SNBr dissolved in 30 ml DMF was added with the help of a dropping funnel. The evolution of gases commenced after 5 min of addition. The gases were passed into the gas traps for 25 min. after which the gas evolution stopped. The contents of the RB flask were heated further for another 30 min., then cooled to room temperature and poured into 200 ml acidified (HCl) ice-cold water giving a solution labelled as solution A_3 .

A 50 ml portion of contents of the conical flask serving as CH_2O trap was taken out for estimation of formaldehyde as described earlier. The yield of formaldehyde thus estimated by preparing its dimedone derivative was found to be 0.05g (8%). The dimedone derivative was characterised by its melting point. $\text{Mp. } 187^\circ$ (found); lit.m.p., 189° . (Dictionary of Organic compounds).

A 50 ml portion of solution A_3 was used for the detection of Br_2 as described earlier.

To the rest of the solution A_3 solid NaOH flakes were added to make it just alkaline. Thereafter 10g of NaCl was dissolved in it. The mixture was then extracted with ether. The ethereal layer

was separated washed with water dried and concentrated. The concentrate was analysed for methanol by GLC (comparison with an authentic sample). The total yield of methanol as contained in solution A_3 was thus estimated to be 35%.

The aqueous layer of the above solution A_3 remaining after extraction with ether was then extracted with CH_2Cl_2 . From the dichloromethane extract, succinimide was isolated and characterised as usual. The total yield of succinimide as contained in original solution A_3 was estimated in this manner to be 0.59g; 66%.

The aqueous layer left after extraction with CH_2Cl_2 was acidified with HCl and the resultant mixture extracted with ether. The ethereal extract was washed with water, dried and evaporated to give glycolic acid. The total glycolic acid content in solution A_3 was thus estimated to be 0.26g; 46%.

CO_2 gas was estimated from the contents of the flask serving as CO_2 trap and found to be 48%.

4. Reaction of potassium salt of glycolic acid (0.005 mol; 0.57g) with SNBr (0.01 mol; 1.78g) under nitrogen atmosphere in dry DMF at reflux temperature.

In a 3-necked RE flask 0.57g (0.005 mol) of potassium salt of glycolic acid was placed. The flask was fitted with a device to add SNBr solution and to pass pure, dry nitrogen, a condenser, device for the absorption of CH_2O and CO_2 and on oil bath as described in the above experiment.

The contents of the RB flask were flushed with N_2 gas for 10 min after which the flask was placed in an oil-bath maintained at a temperature ranging from 70° to 80° . $SNBr$ (1.78g; 0.01 mol) contained in 30 ml of dry DMF was then added to the flask through a dropping funnel.

The gases formed when the reaction commenced after 5 min. were passed first into the CH_2O trap and then into the CO_2 trap. The heating was continued with stirring for 1 h after which the contents were cooled to room temperature and then poured into 200 ml of acidified (HCl) ice-cold water. This solution was labelled solution A_4 .

A 50 ml portion of this solution A_4 was used for the estimation of formaldehyde as described earlier. Total yield of formaldehyde in the entire solution A_4 was estimated to be 0.31g; 55%. Melting point of the dimedone derivative 189° (found); lit.m.p., 189° .

Another 50 ml portion of the solution A_4 was used to test the presence of Br_2 as described earlier.

The rest of the solution A_4 was treated with NaOH flakes to make it just alkaline and NaCl (10g) was dissolved in it. This was then extracted with ether. The ethereal layer was separated, washed with water, dried and concentrated. G.L.C. analysis as usual of this concentrate showed the presence of methanol in 21% yield in the total solution A_4 .

The aqueous layer obtained after the above ether extraction was then extracted with dichloromethane which after separation washing, drying and evaporation of the solvent yielding succinimide which for the entire solution A_4 amounted to 1.41g; 79%. Mp. 123° (found) lit.m.p., 125° .

The aqueous layer after the above extraction with CH_2Cl_2 was acidified with HCl and then again extracted with ether. The washed, dried extract, on evaporation of the ether, gave the starting material as glycolic acid estimated for the entire solution A_4 to be 12% yield; 0.07g. Mp. 77° (found); lit.m.p., 79° .

CO_2 gas estimated in the contents of the flask serving as CO_2 trap was found to be 76%.

5. Reaction of sodium salt of mandelic acid (0.005 mol, 0.87g) with SNBr (0.005 mol; 0.89g) under nitrogen atmosphere in dry DMF at reflux temperature.

In a 3-necked RB flask, mounted over a magnetic stirring base was placed sodium salt of mandelic acid (0.87g, 0.005 mol) and 30 ml of dry DMF. One neck of this RB flask was connected to a CO_2 trap through the upper end of a condenser. The system was then flushed with nitrogen gas passed through a gas passing tube connected to a neck of the RB flask. The contents of the RB flask were then heated in an oil bath maintained at a temperature ranging from 70° to 80° and SNBr (0.89g) dissolved in 30 ml of dry DMF added through a dropping funnel. The gas evolution commencing

after 5 min. of addition continued upto 25 min. The gas that came out was passed into the conical flask containing baryta solution (CO_2 trap). The reaction was allowed to go on for a total period of 1 h. after which contents of the RB flask were cooled to room temperature and poured into 100 ml acidified (HCl) ice-cold water. The resultant solution was labelled solution A_5 .

A 50 ml portion of this solution A_5 was used for the estimation of benzaldehyde as described earlier. Yield as extrapolated for the entire solution A_5 was 0.39g; 13%. Mp. of dimerone derivative - 195° (found); lit.m.p., 195° (Dictionary of organic compounds).

Another 50 ml portion of solution A_5 was used to test presence of Br_2 as described earlier.

The rest of the solution A_5 was treated with NaOH flakes to make it just alkaline then 10g of NaCl were dissolved in it. This solution was extracted with ether and the ethereal layer separated, washed with water, dried and concentrated by evaporation of the ether. This was then analysed by G.L.C. which showed the presence of benzyl alcohol in entire solution A_5 in a total yield of 26%. T.L.C. analysis also indicated the presence of traces of $\text{C}_6\text{H}_5\text{CH}(\text{OH})-\text{CH}(\text{OH})\text{C}_6\text{H}_5$.

The aqueous layer separated above was extracted with CH_2Cl_2 . The CH_2Cl_2 layer, on separation drying and evaporation of the solvent gave succinimide which on extrapolation for the entire

solution A₅ corresponded to an overall yield of 0.55g; 62%.
Mp. 123° (found); lit. m.p., 125°.

The aqueous layer obtained after extraction with CH₂Cl₂ was acidified with HCl and extracted with ether. This ethereal extract on evaporation of the solvent gave mandelic acid which on extrapolation of the yield for entire solution A₅ corresponded to 0.39g; 45%.

CO₂ was estimated as described earlier using the contents of the CO₂ trapping flask and found to be in an overall yield of 49%.

6. Reaction of sodium salt of mandelic acid (0.005 mol; 0.87g) with SNBr (0.01 mol, 1.78g) under nitrogen atmosphere in dry DMF at reflux temperature.

Sodium salt of mandelic acid (0.87g, 0.005 mol) in dry DMF (30 ml) was placed in a 3-necked RB flask mounted over a magnetic stirring base in an apparatus assembly as described above. Pure, dry nitrogen was passed into the RB flask after which the contents of the flask were heated in an oil-bath maintained at a temperature ranging from 70° to 80°. SNBr (1.78g, 0.01 mol) dissolved in 30 ml of dry DMF was then added to the RB flask. Gas evolution was observed after 5 min. The gas was passed into a conical flask containing 75 ml of standard Ba(OH)₂·8H₂O solution serving as CO₂ trap. The reaction was allowed to go on for 1 h. after which the contents of the RB flask were cooled to room temperature and then

poured into 200 ml of acidified (HCl) cold water. This resultant mixture was labelled as solution A₆.

A 50 ml portion of this solution A₆ was used for the estimation of benzaldehyde in the form of dimedone derivative as described earlier. Total yield of the aldehyde corresponding to the entire solution A₆ was estimated to be 0.57g; 65%.

Another 50 ml portion of solution A₆ was used to test the presence of Br₂ as described earlier.

To the rest of the solution A₆, solid NaOH flakes were added to make the solution just alkaline. NaCl (10g) was also dissolved in it. This mixture was then extracted with ether. The ethereal layer was separated, washed with water and dried. The ethereal extract was concentrated. G.L.C. analysis of the concentrate indicated the presence of benzyl alcohol which corresponded to a total yield of 6% in the entire solution A₆.

The aqueous layer remaining after the extraction with ether was extracted for a second time with CH₂Cl₂. The CH₂Cl₂ layer on separation and evaporation yielded succinimide which corresponded to the total yield of 1.48g; 83% in the entire solution A₆.

The aqueous layer after extraction with CH₂Cl₂ was slightly acidified with HCl and extracted with ether. The dried ethereal extract on evaporation of the solvent yielded mandelic acid the total yield of which corresponding to the entire solution A₆ was 0.09g; 10%.

CO_2 was estimated to be in the yield of 85% as described earlier.

7. Reaction of potassium salt of benzilic acid (0.005 mol, 1.83g) with SNBr (0.005 mol; 0.89g) under nitrogen atmosphere in dry DMF at reflux temperature.

Potassium salt of benzilic acid (1.83g; 0.005 mol) and 30 ml of dry DMF was placed in a 3-necked RB flask mounted over a magnetic stirring base in an assembly of apparatus as described above. Pure, dry nitrogen was flushed into the flask for 10 min. after which the contents of the flask were heated in an oil-bath, maintained within a temperature range of 70° to 80° . A solution of SNBr (0.89g; 0.005 mol) in dry DMF (30 ml) was then added through a dropping funnel with continuous stirring and the reaction was allowed to continue for 1 hr. Gas evolved was passed into the $\text{Ba}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ solution (CO_2 trap). Total yield of CO_2 was estimated as mentioned earlier was found to be 47%. The contents of the flask were, after the specified period of heating, cooled to room temperature and poured into ice-cold water acidified with HCl . A white precipitate which appeared was separated by filtration and found to be benzophenone (0.33g; 18%) identified by means of 2:4 DNP derivative. The filtrate obtained was labelled as solution A_7 .

A 50 ml portion of solution A_7 was used for testing the presence Br_2 .

The remaining solution A_7 was made alkaline by the addition of NaOH flakes. To this, 10g of NaCl was added and this mixture extracted with ether. Ethereal layer, after washing with water, drying and concentration was subjected to GLC analysis showed the presence of benzhydryl alcohol the yield of which on extrapolation for the entire solution A_7 was found to be 19%. TLC of the concentrate also indicated the presence of small amounts of $(C_6H_5)_2C(OH)-C(OH)(C_6H_5)_2$.

The aqueous layer remaining above was extracted with CH_2Cl_2 . The purified extract, on evaporation of the solvent, gave succinimide which for the entire solution A_7 corresponded to an yield of 0.53g; 60%. The aqueous layer left after the above extraction with CH_2Cl_2 was acidified with HCl. Benzilic acid which precipitated out was washed, dried and weighed. The total yield of benzilic acid estimated for the entire solution A_7 was 0.81g; 44%.

8. Reaction of potassium salt of benzilic acid (0.005 mol; 1.83g) with S_NBr (0.01 mol; 1.78g) under nitrogen atmosphere in dry DMF at reflux temperature.

In a 3-necked RB flask mounted over a magnetic stirring base and fitted with apparatus assembly as described above was placed 1.83g; 0.005 mol of potassium salt of benzilic acid in 30 ml of dry DMF. Pure dry N_2 was passed through a gas passing tube for 10 min. The flask was then heated in an oil-bath maintained at a temperature ranging from 70° to 80° . S_NBr (1.78g; 0.01 mol)

dissolved in 30 ml of dry DMF was added to the flask with continuous stirring. The reaction commenced with evolution of gas which was passed into the $\text{Ea}(\text{OH})_2 \cdot 8\text{H}_2\text{O}$ solution acting as CO_2 trap as mentioned in earlier experiments. After 1 h, the contents of the flask were cooled to room temperature and poured into 200 ml of acidified (HCl) ice-cold water. A white precipitate which separated was filtered off and identified to be benzophenone in 79% (1.45g) yield. The filtrate was labelled as solution A_8 .

A 50 ml portion of the solution A_8 was used to test presence of Br_2 .

The rest of the solution A_8 was made alkaline by adding NaOH flakes and 10g of NaCl added to it. The mixture was extracted with ether. The ethereal layer was separated, washed with water, dried, concentrated and the concentrate subjected to G.L.C. and T.L.C. analysis. These analyses did not indicate the presence of any organic products.

The aqueous layer left in the above extraction was again extracted with CH_2Cl_2 . The dichloromethane layer after washing with water, drying and concentration showed, on TLC analysis, the presence of succinimide. Total yield extrapolated for the entire solution A_8 was 1.53g; 86%.

The remaining aqueous layer, after extraction with CH_2Cl_2 was acidified with HCl. A precipitate which separated out was

identified as benzilic acid. The total amount of benzilic acid estimated by extrapolation for the entire solution A_8 was 0.18g; 10%.

CO_2 was estimated as described earlier. It was found to be in 88% yield.

9. Reaction of potassium salt of benzilic acid (0.005 mol; 1.83g) with $SNBr$ (0.005 mol; 0.89g) under oxygen atmosphere in dry DMF at reflux temperature.

Reaction was carried out in a manner similar to that described above for reaction 8, excepting that instead of providing nitrogen atmosphere an oxygen atmosphere was created and the molar ratio of the two reactants were different. Analysis of the reaction mixture carried out as described for run 8 gave the following yields of different products:

Benzophenone	-	0.82g; 45%
Succinimide	-	0.43g; 48%
Benzilic acid	-	0.82g; 45%
CO_2	-	45%.

Formation of Br_2 was noticed in this reaction also.

10. Reaction of potassium salt of benzilic acid (0.005 mol; 1.83g) with $SNBr$ (0.005 mol; 0.89g) in dry DMF medium under nitrogen atmosphere with a 150-W bulb placed 1 ft. away and stirring for 12 h.

Reaction was carried out in a similar manner as described

for run 7 excepting that the contents of the reaction flask were not heated but a 150-W bulb was illuminated from a distance of 1 ft. and stirring at room temperature was continued for 12 h. Workup of the reaction mixture and product analysis as usual indicated the following yields of the products:

Benzophenone	- 0.11g; 6%
Benzhydryl alcohol	- 8% (by G.L.C.)
Succinimide	- 0.41g; 46%
Benzilic acid	- 1.48g; 81%
CO ₂	- 12%.

Presence of Br₂ as a product was also detected as in the usual manner.

11. Reaction of potassium salt of benzilic acid (0.005 mol; 1.83g) with SNBr (0.01 mol; 1.78g) under nitrogen atmosphere in dry DMF at reflux temperature for 6 h.

The reaction was carried out as in the run 8 excepting that the reaction time was increased to 6 h. Product analysis as usual indicated the yields of the products to be as follows:

Benzophenone	- 1.59g; 87%
Succinimide	- 1.60g; 90%
CO ₂	- 89%.

Test for the presence of Br₂ in the reaction mixture was found to be positive.

12. Reaction of potassium salt of benzoic acid (0.005 mol; 1.83g) with SBr (0.01 mol; 1.78g) under nitrogen atmosphere and with stirring at room temperature for 12 h.

Potassium salt of benzoic acid (1.83g; 0.005 mol) and SBr (1.78g; 0.01 mol) taken in 60 ml of dry DMF were stirred at room temperature under nitrogen atmosphere for 12 h. No evolution of gas (CO_2) was observed. Analysis of the reaction mixture in the usual way showed that no reaction had occurred at all.

13. Reaction of potassium salt of glycolic acid (0.005 mol; 0.57g) with SBr (0.01 mol; 1.78g) under nitrogen atmosphere in the presence of 0.01 mol cumene and dry DMF medium at reflux temperature for 1 h.

In a 3-necked RB flask was placed 0.57g (0.005 mol) of potassium salt of glycolic acid, 0.01 mol cumene and 30 ml of dry DMF. Nitrogen was passed into the RB flask mounted over a magnetic stirring base as fitted with other usual experimental assembly. The contents were heated in an oil bath as mentioned for earlier experiments and SBr (1.78g) dissolved in 30 ml of dry DMF added to the flask. Heating was continued and reaction allowed to continue for 1 h. Gas evolved during the reaction was trapped in the baryta solution as before. The workup of the reaction mixture and product analysis as described for run 4 indicated the following yields.

Formaldehyde - 0.10g; 18%

Methanol - 56% (by G.L.C.)

Succinimide - 1.42g; 80%

Glycolic acid- 0.07g, 13%

CO_2 - 78%

Presence of Br_2 formed as a product was also confirmed by the method described earlier.

14. Reaction of potassium salt of glycolic acid (0.005 mol, 0.57g) with SNBr (0.005 mol; 0.89g) under nitrogen atmosphere in the presence of 0.01 mol cumene in dry DMF medium at reflux temperature for 1 h.

The reaction was carried out as in the case of run 13 excepting that the molar ratio of potassium salt of glycolic acid and SNBr was 1:1. Product analysis as described for run 3 indicated the following yields of various products:

Methanol - 41%

Succinimide - 0.41g; 46%

Glycolic acid - 0.26g; 46%

CO_2 - 48%.

It was qualitatively verified that Br_2 was also formed as one of the products.

15. Reaction of potassium salt of benzilic acid (0.005 mol; 1.83g) with p-Nitrobenzenediazonium fluoroborate (0.005 mol; 1.185g) under nitrogen atmosphere in dry DMF at room temp. (30^o) for 1hr.

In a 3-necked RB flask mounted on a magnetic stirring base and fitted with a N₂ gas inlet, a dropping funnel and a condenser connected to a N₂ gas collector through a CO₂ gas trapping conical flask containing standard baryta solution was placed 1.83g (0.005 mol) of sodium salt of benzilic acid dissolved in 30 ml of dry DMF. The system was flushed with pure, dry nitrogen gas to provide initial nitrogen atmosphere inside the reaction flask. On the addition of p-nitrobenzenediazonium fluoroborate (0.005 mol) contained in 30 ml of dry DMF through the dropping funnel to the contents of the reaction flask under stirring, evolution of gases started instantaneously and continued for about 30 min. The gases consisting of a mixture of CO₂ and N₂ were passed through the baryta solution which absorbed carbon dioxide and let the nitrogen pass through to the N₂ gas collector. After stirring for a total period of 1 h, the reaction mixture was poured into ice cold water. The mixture was made alkaline by the addition of NaOH flakes and thereafter extracted with ether. The ethereal layer was separated, washed with water, dried and concentrated by the evaporation of the solvent. The concentrate on GLC analysis indicated that nitrobenzene (78%) was formed in the reaction. TLC indicated the presence of benzophenone in the concentrate. Benzophenone was isolated by means of chromatography over silica gel column. The

yield of benzophenone was found to be 21% of the theoretical. The aqueous layer remaining after extraction with ether was then made acidic when a white precipitate of benzoic acid separated out. This precipitate was washed with water, dried and weighed for the determination of the yield which was found to be 48% of the theoretical. The yields of CO_2 and N_2 gases evolved were computed to be 46% and 80%, respectively.

16. Reaction of potassium salt of benzoic acid (0.005 mol; 1.83g) with p-nitrobenzenediazonium fluoroborate (0.01 mol, 2.370g) under nitrogen atmosphere in dry DMF at room temperature (30°) for 1 hr.

This reaction was performed using 0.01 mol of p-nitrobenzenediazonium fluoroborate and 0.005 mol of the potassium salt of benzoic acid under otherwise similar conditions to those employed for the above mentioned reaction 15. Workup and analysis of the reaction mixture in the same way indicated that no benzoic acid was present among the products. The yields of the other products was found to be as follows:

Nitrobenzene	-	85%
Benzophenone	-	80%
CO_2 gas	-	84%
N_2 gas	-	89%

III.5 References

1. C. Djerassi, Chem. Revs., 43, 271 (1948).
2. L. Horner and E.H. Winkelmann, Newer Methods Prep. Org. Chem., 3, 151 (1964).
3. H.J. Dauben Jr. and L.C. McCoy, J. Am. Chem. Soc., 85, 3052 (1963).
4. G.F. Bloomfield, J. Chem. Soc., 114 (1944).
5. J. Adam, P.A. Gosselain and P. Goldfinger, Nature, 171, 704 (1953).
6. K.J. Shea, D.C. Lewis and P.S. Skell, J. Am. Chem. Soc., 95, 7768 (1973).
7. (a) R.E. Pearson and J.C. Martin, J. Am. Chem. Soc., 85, 354, 3142 (1963).
 (b) G.A. Russell, et.al. J. Am. Chem. Soc., 85, 365, 3139, 3129, 2850 (1963).
 (c) J.H. Incremona and J.C. Martin, J. Am. Chem. Soc., 92, 627 (1970).
8. F.L.J. Sixma and R.H. Riem, Proc. Koninkl. Akad. Wetenschap, 61B, 183 (1958); Chem. Abstr., 53, 2123 (1959).
9. B.P. McGrath and J.M. Tedder, Proc. Chem. Soc., 80 (1961).
10. R. Filler, Chem. Revs., 63, 21 (1963).
11. A. Schönberg, R. Moubasher and M.Z. Barakat, J. Chem. Soc. 2504 (1951).
12. N. Konigeberg, G. Stevenson and J.M. Luck, J. Biol. Chem., 235, 1341 (1960).

13. John E. Barry and Lennart Ebersson, *Tetrahedron Letters*, 25, 2847-2850 (1984).
14. J.E. Barry, M. Finkelstein, *J. Org. Chem.* (1982), 47, 1292.
15. E. Campaigne and W.M. LeSeur, *J. Am. Chem. Soc.*, 70, 1555 (1948).
16. K. Dittmer, R.P. Martin, W. Herz and S.J. Cristol, *J. Am. Chem. Soc.*, 71, 1201 (1949).
17. C. Goissis, *Tetrahedron Lett.*, 4821 (1982).
18. N.B. Chapmann and J.F.A. Williams, *J. Chem. Soc.*, 5044(1952).
19. D.L. Comis and R.E. Lyle, *J. Org. Chem.*, 41, 2065 (1976).
20. M.I. Abd El-Wahab and M.Z. Barakat, *Monatsch.*, 88, 692(1957).
21. W. Growbel, *Chem. Ber.*, 93, 284 (1960); *Chem. Abstr.*, 54, 9816 (1960).
22. K.C. Schrieber and V.P. Fernandez, *J. Org. Chem.*, 26, 2478 (1961).
23. W. Tagaki, K. Kikukawa, K. Ando and S. Oae, *Chem. and Ind. (London)*, 1624 (1964).
24. R.L. Huang and K.H. Lee, *J. Chem. Soc.*, 5947-5963 (1964).
25. G. Rosini, *J. Org. Chem.*, 39, 3504 (1974).
26. (a) M.Z. Barakat, M.F.A. Et-Wahab and M.M. Et-Sada, *J. Am. Chem. Soc.*, 77, 1670 (1955).
 (b) M.Z. Barakat and M.F.A. Et-Wahab, *J. Am. Chem. Soc.*, 75, 5731 (1953).
27. R.A. Barnes and G.R. Bulkwater, *J. Am. Chem. Soc.*, 73, 3858 (1951).
28. J.H. Looker and M.J. Holm, *J. Org. Chem.*, 24, 567 (1959).
29. *Bull., Inst. Chem. Acad. Sinica*, 21, 56-61 (1972).

30. Chem. Abs., 1973, 79 126139b.
31. Yehuda Yanuka, Robert Katz and Snalom Sarā., I.L. 1725(1968).
32. Dominic Ip and Jan Rocek., J. Am. Chem. Soc., 101 21, 6311 (1979).
- 33.(a) E. Medaya, R.L. Hinman and S. Theodoropoulos, J. Am. Chem. Soc., 86, 2727 (1964).
(b) E. Medaya, R.L. Hinman and S. Theodoropoulos, J. Am. Chem. Soc., 85, 3052 (1963).
34. J.C. Martin and P.D. Bartlett, J. Am. Chem. Soc., 79, 2533 (1957).
35. H.W. Johnson Jr. and D.E. Bublitz, J. Am. Chem. Soc., 79, 753 (1957).
- 36.(a) P.S. Skell and J.C. Day, Acc. Chem. Res., 11, 381 (1978).
(b) P.S. Skell and J.C. Day, J. Am. Chem. Soc., 100, 1951 (1978).
37. A.G. Davies, B.P. Roberts and J.N. Smith, J. Chem. Soc., Perkin Trans.II, 2221 (1972).
38. M.Z. Barakat and G.M. Mousa, J. Pharm and Pharmacol., 4, 582 (1952).
39. M.L. Poutsma, Free Radicals, 2, 211 (1973).
40. J.R. Shelton and C. Ciadella, J. Org. Chem., 23, 1128(1958).
41. N.A. Label, J.E. Huber and L.H. Zalkow, J. Am. Chem. Soc., 84, 2226 (1962).
42. E.E. Van Tamelen and E.J. Hessler, Chem. Comm., 413 (1966).
- 43.(a) V. Thiagarajan and N. Venkatasubramanian, Ind. J. Chem., 8, 809 (1970).
(b) G. Langbein and B. Steinert, Chem. Ber., 95, 1873 (1962), Chem. Abstr., 58, 430 (1963).

44. Krause, P.F. Geurkink and Grist., J. Am. Chem. Soc., 76, 5796 (1954).
45. N. Venkatasubramanian, V. Thiagarajan., Ind. J. Chem., 7, 830 (1969).
46. Kalyan K. Banerji, Zeitschrift für Naturforschung, Teil B. 1973, 28 (7-8) 450(Eng).
47. G. Gopalkrishnan and John L. Hogg, J. Org. Chem., (1985), 50, 1206.
48. J.M. Furhop and D. Mauzerall, J. Am. Chem. Soc., 90, 3875 (1968).
49. G.P. Chalfont and M.J. Perkins, J. Chem. Soc.(B) 401 (1970).
50. V.M. Clark, M.R. Eraut and D.W. Hutchinson, J. Chem. Soc.(C), 79 (1969).
51. Lecomite, J. and Gault, H, Compt. rend. 238, 2538 (1954).
52. Fieser, L.F. and Rajagopalan S.J. Am. Chem. Soc., 71, 3935 (1949).
53. Fieser, L.F. and Rajagopalan, S. J. Am. Chem. Soc., 72, 5530 (1950).
54. Jones, D.N., Lewis, J.P., Shopper, C.W. and Summer, G.H.R. J. Chem. Soc. 2876 (1955).
55. Fieser, L.F. and Rajagopalan, S., J. Am. Chem. Soc., 71, 3938 (1949).
56. Kowanami, J. Bull. Chem. Soc. Japan, 34, 671 (1961); 56:11662.
57. Barakat, M.Z. and Mousa, G.M., J. Pharm. Pharmacol., 4, 115 (1952), 46:7998.
58. Grob, C.A. and Schmid, H.U. Experimentia, 5, 199 (1949); 44:1890.

59. Saigusa, T. and Oda, R., J. Chem. Soc. Japan, Ind. Chem. Soc. 57, 950 (1954); 49:11317.
60. Barakat, M.Z., El-Wahab, M.F.A. and El-Sada, M.M., J. Am. Chem. Soc., 77, 1670 (1955).
61. Snyder, H.R., Carpino, L.A. Zack, J.F. Jr and Mulls, J.F., J. Am. Chem. Soc. 79, 2556 (1957).

CHAPTER-IV

REDUCTION OF PRIMARY BENZYLIC HALIDES WITH SODIUM NAPHTHALENE

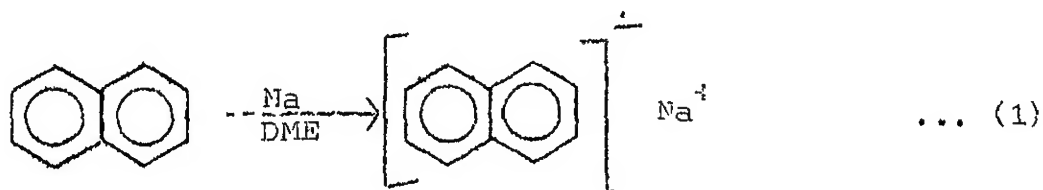
IV.1 Abstract

Reactions of sodium naphthalene with equimolar quantities of benzyl chloride, p-nitrobenzyl bromide, 1-chloromethyl naphthalene, 9-chloromethyl anthracene in THF at temperatures ranging from -10° to 0°C under nitrogen atmosphere have been examined with a view to elucidating their mechanisms. While initial generation of free radical intermediates as a consequence of electron transfer is believed to occur in all the reactions, carbanions produced by subsequent reduction of radicals (by electron transfer) are also found to intervene. Although sodium naphthalene is capable of acting both as an electron donor (reducing agent) and as a base, the latter role of this reagent is evident only in its reaction with p-nitrobenzyl bromide containing fairly acidic benzylic protons. Carbanion intermediates have been trapped in the form

of the corresponding Grignard reagents using MgBr_2 in the reactions of benzyl chloride and 9-chloromethylanthracene. A process, involving a carbene intermediate, occurring simultaneously with those involving radical and carbanion intermediates has been proposed in the case of p-nitrobenzyl bromide. Appropriate mechanistic steps rationalising the relevant observations have been outlined.

Iv.2 Introduction

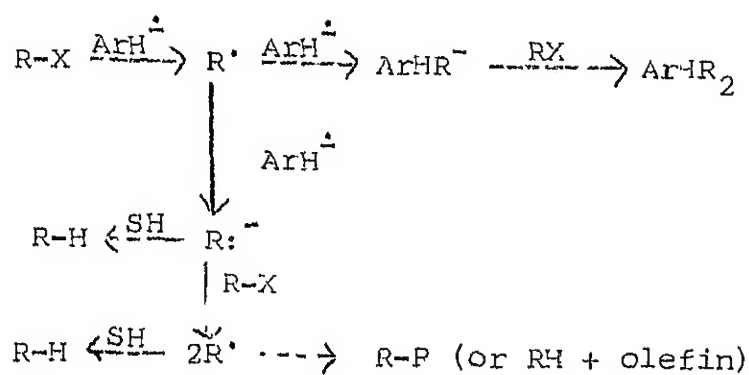
Alkali metals are known to reduce aromatic hydrocarbons¹⁻³ producing radical anions. For example, reduction of naphthalene⁴ with sodium yields sodium naphthalene (Eqn.1).



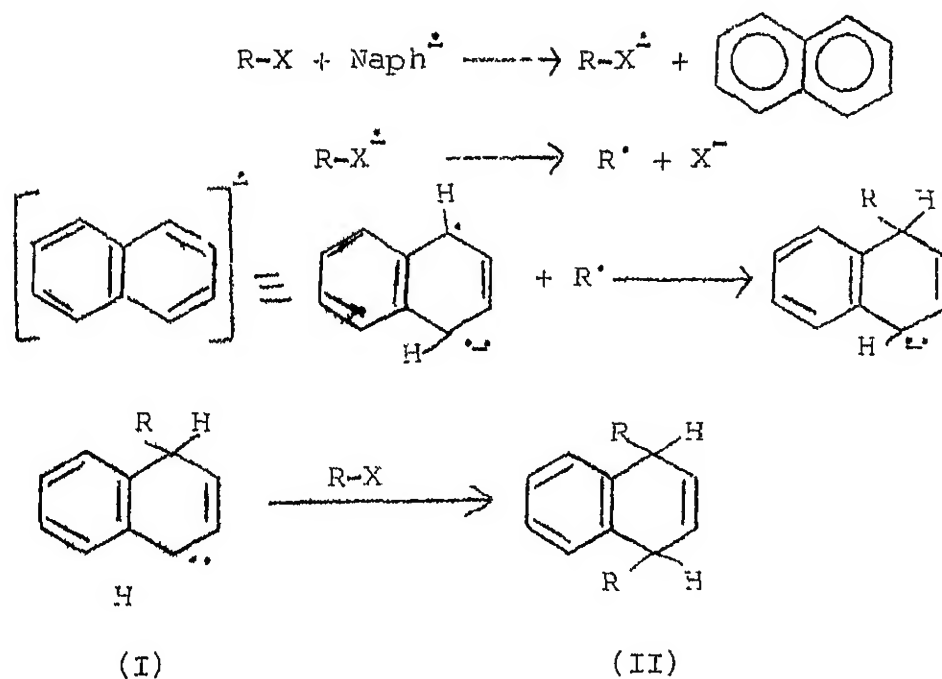
These radical-anions can either act as strong bases and abstract protons from weakly acidic substrates or as single electron donors to appropriate substrates.

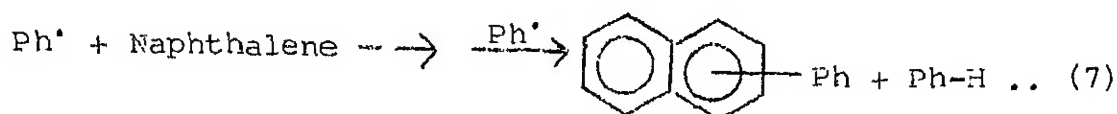
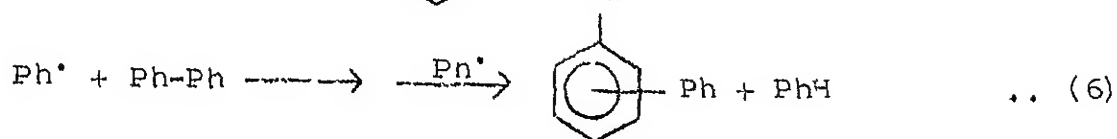
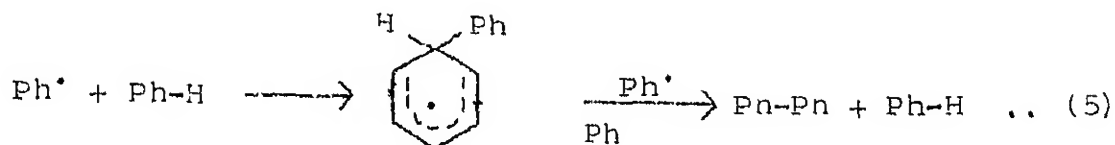
Reactions of alkyl halides with aromatic radical-anions have been thoroughly investigated and reviewed.⁵⁻⁷ The general mechanism of these reactions is outlined in Scheme IV.1.

SCHEME IV.1

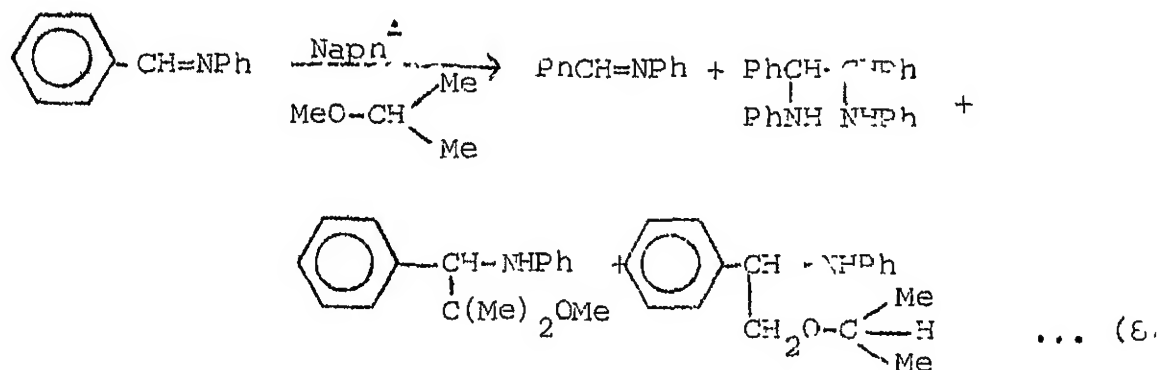


Alkylation of aromatic nuclei proceeds via the coupling of alkyl radicals with aromatic radical-anions. For example, reaction of sodium naphthalene with R-X first produces anion(I) which, by a subsequent S_N2 displacement on the alkyl halide gives dialkylates^{8,9} (II).



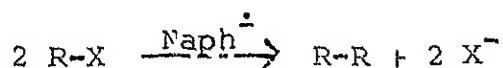


Similar radical mechanism has been proposed by Linitz and Ho²⁰ to explain their observations in the reaction of benzalaniline with sodium naphthalene (Eqn.8).



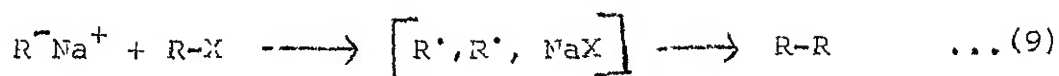
Reaction of σ -chlorobenzalaniline with sodium naphthalene also appears to proceed in the same way.

Of various reactions of alkyl halides, reductive dimerization is the least understood:

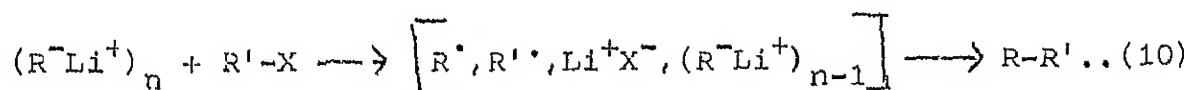


Both radicals²³ and anions²⁴ are proposed as intermediates in the formation of dimers. The most acceptable explanation for the

rapid rate of alkyl dimer formation is the coupling of geminate radical pairs²⁴ as shown in(Eqn.9).

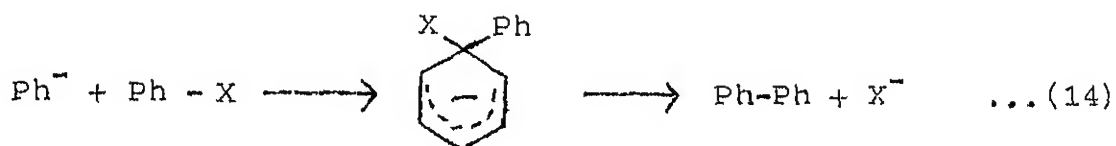
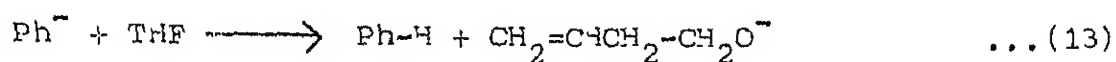
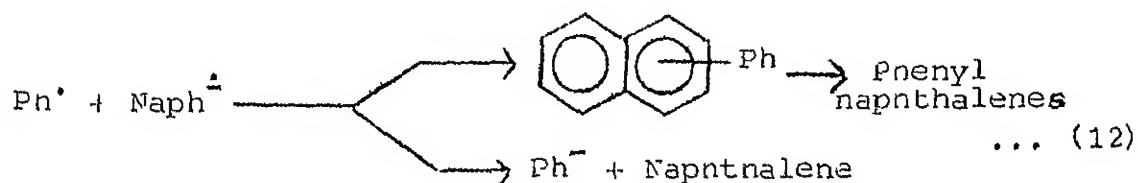
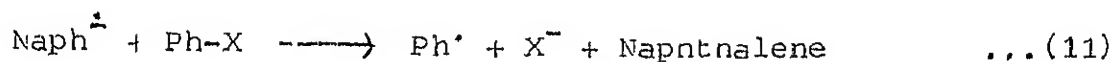


In this respect, the above reaction is parallel to that of alkyl lithiums with alkyl halides (Eqn.10):



The radical pairs generated by electron transfer from alkyl lithium to the alkyl halide in solvent cage, may couple, disproportionate or diffuse apart. The intermediate radicals formed in this reaction have been trapped²⁵ and detected by means of ESR spectroscopy.^{26, 27} Dimerization has also been observed in the reduction of alkyl halides with metal complexes.²⁸ Cyclopropyl halides are also reduced by alkali metal naphthalenes.²⁹

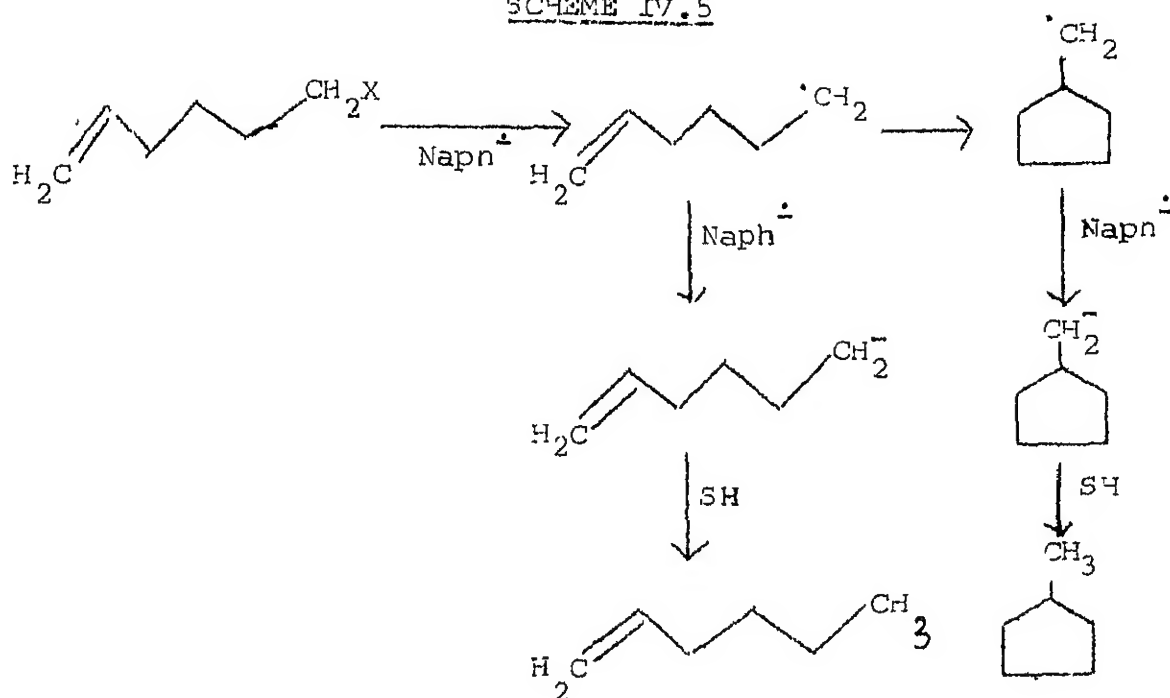
Sargent¹⁵ has studied the reactions of sodium naphthalene with halobenzenes and suggested an alternative mechanism involving aryl anions as effective intermediates as shown in Scheme IV.4.

SCHEME IV.4

Singh and Kumar¹³ have also presented evidence in favor of the existence of aryl anions in the reactions of chloroaromatics with sodium naphthalene.

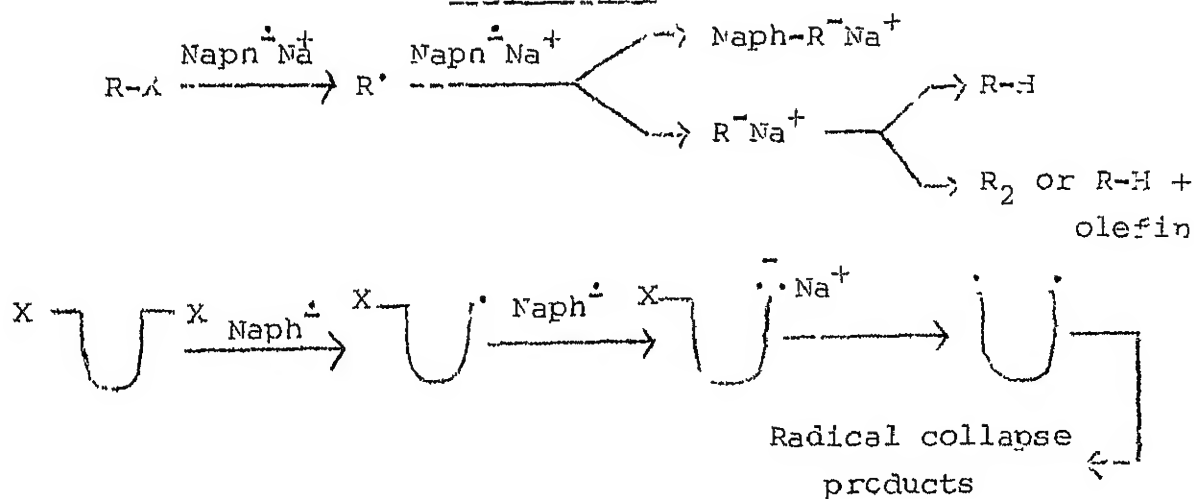
That radicals and anions are probable intermediates^{10, 5a} in the reactions of sodium naphthalene with 5-hexenyl halides, has been supported by the production of both methyl cyclopentane and hex-1-ene where cyclization of 5-hexenyl radicals competes with their reduction to anions as illustrated in Scheme IV.5.

SCHEME IV.5



Radicals are found to be the intermediates in the reaction of triphenylsilyl halides with sodium naphthalene³⁰. Garst and coworkers have proposed the occurrence of anion intermediates in the reactions of α,ω -dihaloalkanes.^{24b,31} The mechanism suggested by these workers is outlined in Scheme IV.6.

SCHEME IV.6

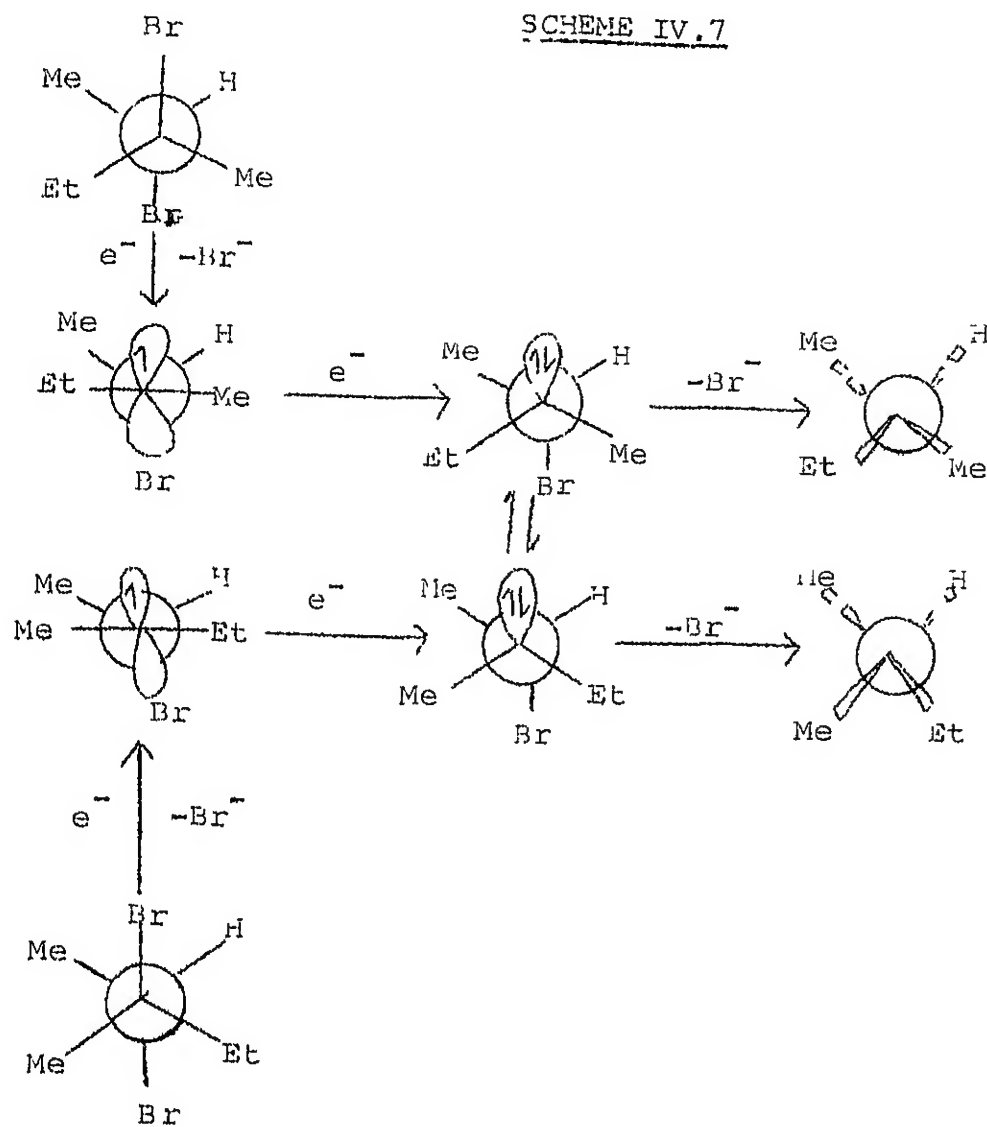


The reaction of 1,4- and 1,5-dihaloalkanes gives mostly cycloalkanes, olefins and alkylated naphthalenes; but, no dimeric or polymeric residues of dihaloalkanes are obtained.^{24b} This is in conformity with the idea that initially formed alkyl radicals do not couple, but react with an additional molar equivalent of sodium naphthalene to give alkyl anions and alkylated naphthalene anions. However, 1,6-dihaloalkanes, unlike 1,4- and 1,5-dihaloalkanes, react with sodium naphthalene to give significant amounts of dimeric products in addition to the four monomeric reduction products.³¹ Intermediacy of anions has been further supported with the help of CIDNP studies using ^{19}F probe.³²

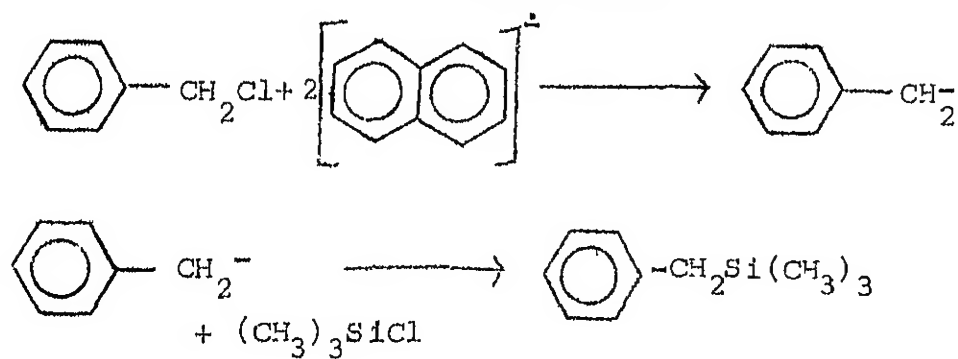
Dehalogenation of vic-dihalides by sodium naphthalene to give olefins has also been observed.^{9,33-36} Stereospecific dehalogenation of the vic - dihalides shown in Scheme IV.7 has been reported by W. Adam and J. Arce.¹⁶

Although the reactions of purely alkyl halides as well as aryl halides with sodium naphthalene have been examined in details, there are very few reports on the sodium naphthalene reductions of benzylic halides. Bank and Bank¹⁷ have provided evidence in favour of anion intermediates in the reaction of benzyl chloride with $\text{Naph}^{\cdot-}$. Benzyltrimethyl silane was obtained when sodium naphthalene in THF was added to a pre-mixed solution of benzylchloride and trimethylsilyl chloride as shown in Scheme IV.8.

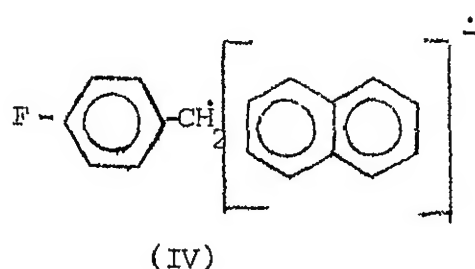
SCHEME IV.7



SCHEME IV.8

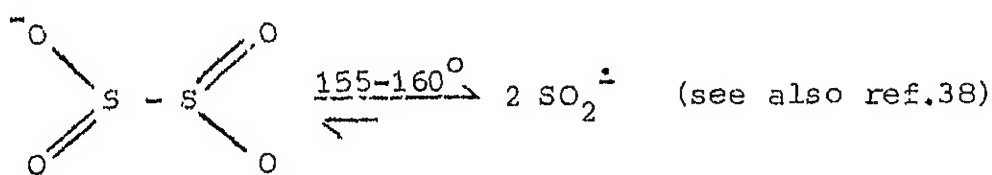


Reduction of p-fluorobenzyl chloride with $\text{Naph}^{\cdot-}$ forms an intermediate which has been assumed by Raksnys³² to be consistent with the collisional pair (IV) of p-fluorobenzyl radical and naphthalene radical-anion



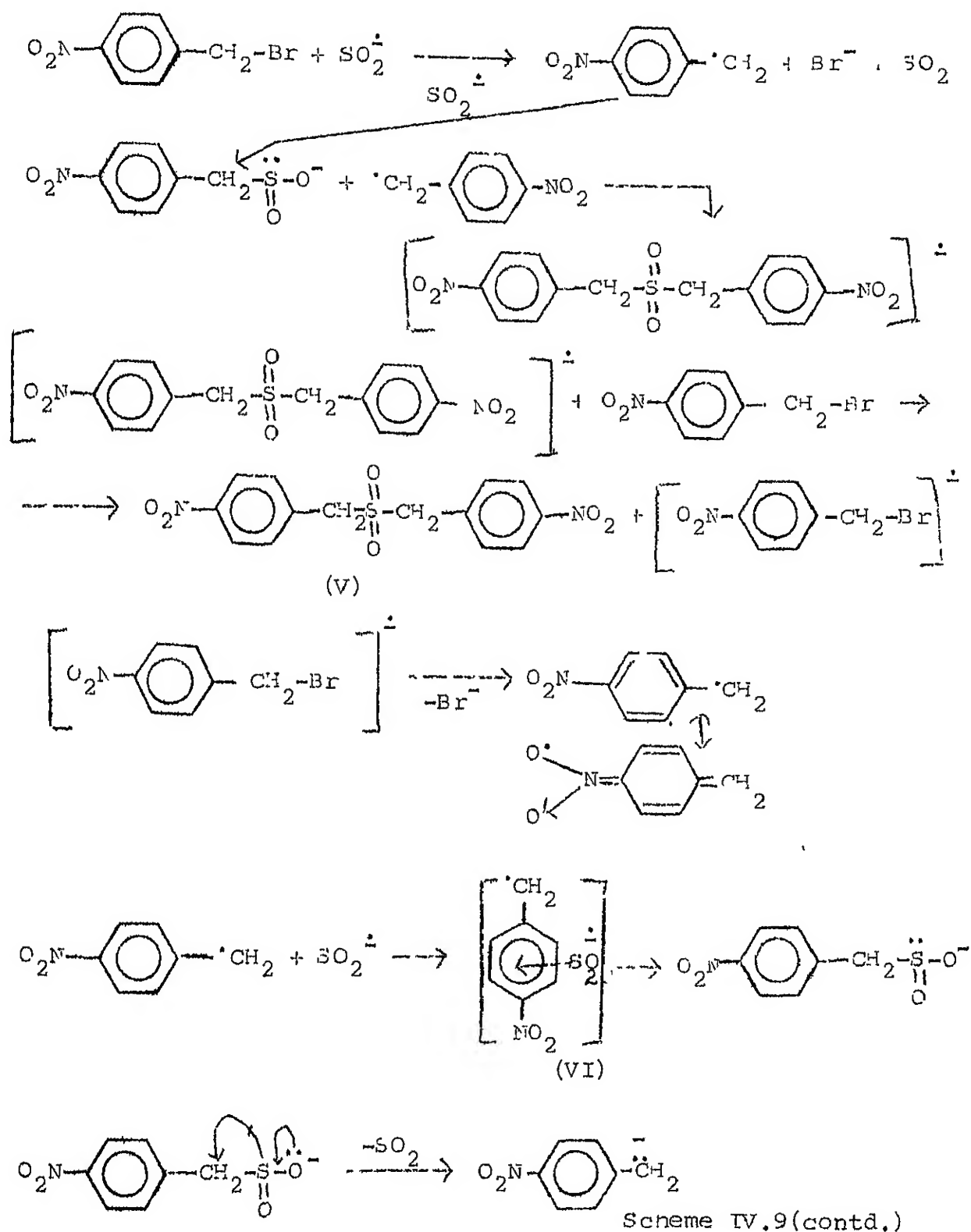
A novel electron transfer mechanism has been suggested by Singh and coworkers³⁷ for the reduction of benzylic halides with various reagents like lithium aluminium hydride (LAH), sodium dithionite, Grignard reagents and Fe(II). The mechanism proposed by them for the reduction using sodium dithionite is outlined in Scheme IV.9.

SCHEME IV.9

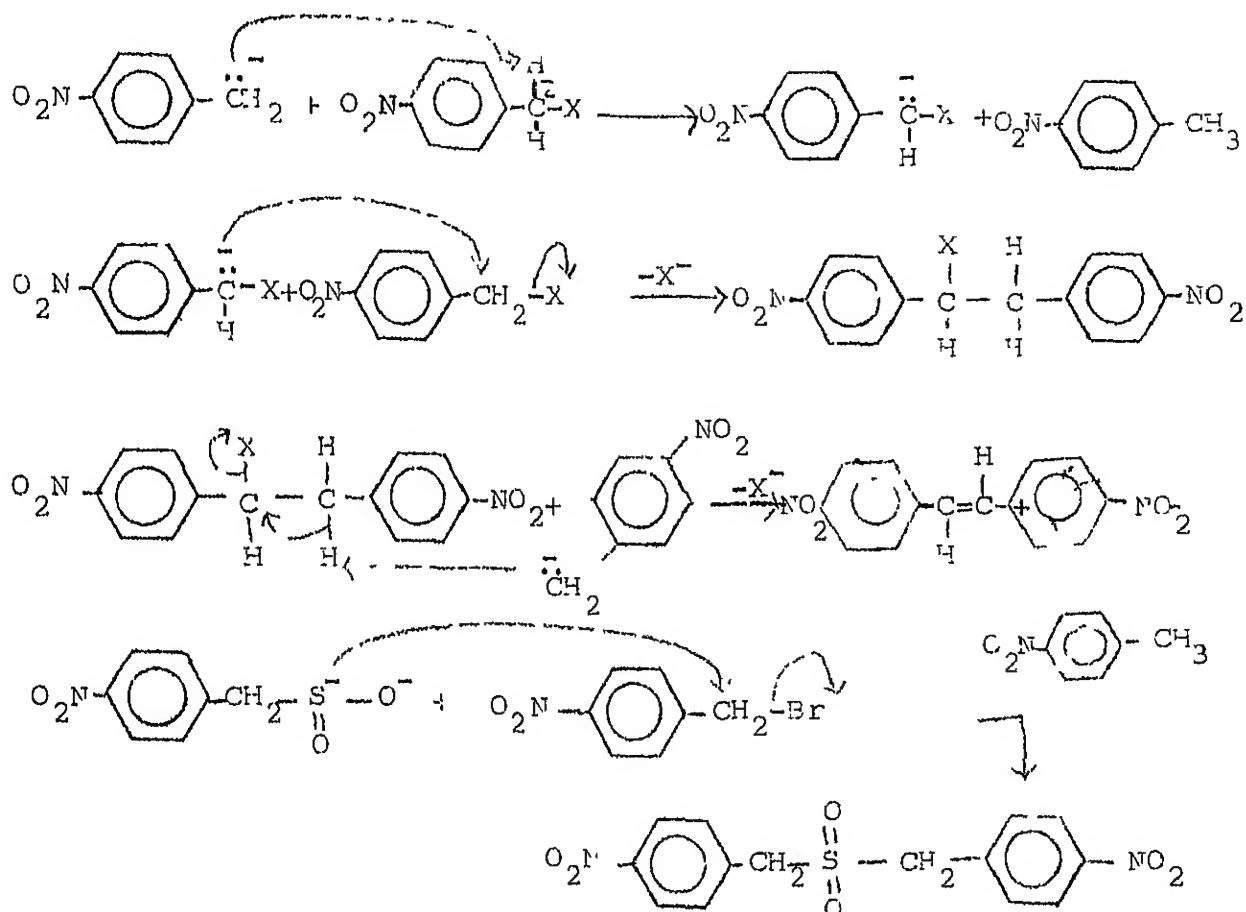


Scheme IV.9(contd.)

Scheme IV.9(contd.)

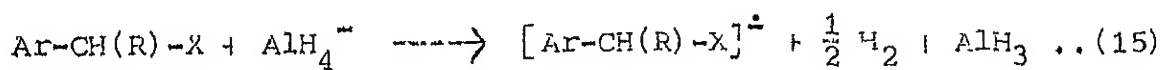


Scheme IV.9 (contd.)



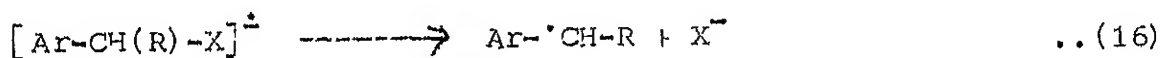
Singh and coworkers have also found that the reactions of benzylic halides with lithium aluminium hydride (LAH) follow the mechanism illustrated in Scheme IV.10.

SCHEME IV.10



(VII)

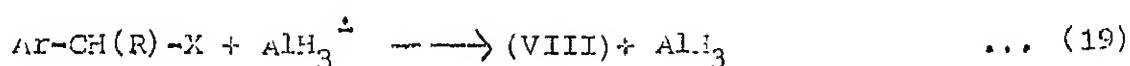
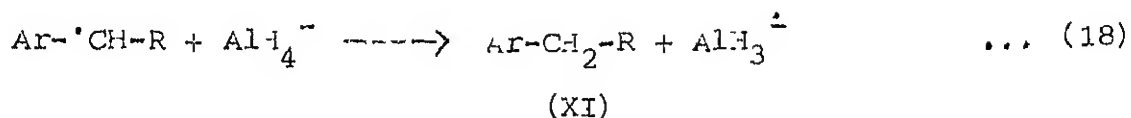
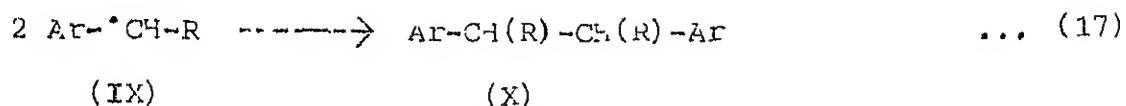
(VIII)



(VIII)

(IX)

Scheme IV.10 (contd.)

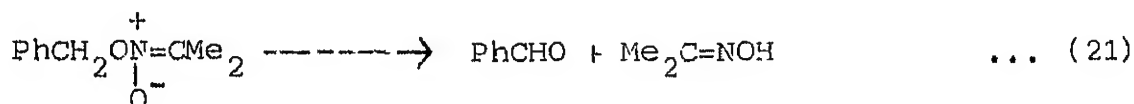
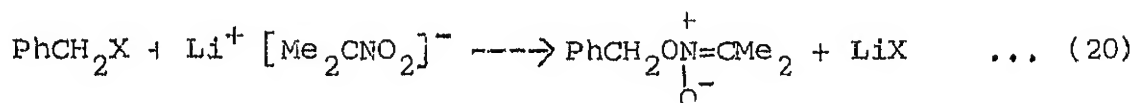
Scheme IV.10 (contd.)

According to the authors, radical-anion (VIII), after formation, dissociates to give the free radical (IX) (Eqn.16). The benzylic radicals (IX) are known to prefer dimerization as shown in (eqn.17) rather than hydrogen abstraction from the solvent THF,³⁹ quantity of hydrogen gas evolved is in accordance with (eqn.15) on one hand and the formation of substantial amounts of (XI) on the other makes the occurrence of hydrogen atom abstraction process represented by (eqn.18) obvious. Abstraction of a hydrogen atom by radical species from AlH_4^- is precedented.⁴⁰⁻⁴² Besides producing monomeric reduction product (XI), (eqn.18) generates the radical anion $\text{AlH}_3^{\cdot-}$ which competes with AlH_4^- in donating an electron to the starting organic halide. Combination of (eqns. 15-19) accounts for the involvement of only one out of the four hydrogens available in AlH_4^- in the reduction process. But the consumption of significantly more than 50 percent of (VII) using only half the molar equivalent of LAH and similarly, significantly more than 25 percent of (VII) using only one-fourth molar equivalent of the reducing

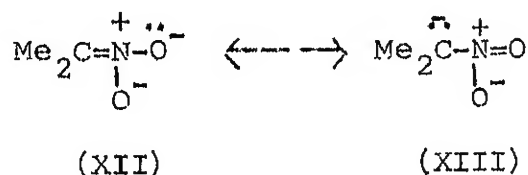
agent indicated the utilization of the remaining hydrogens of AlH_3 in these cases.

Intervention of free radicals similarly, has been demonstrated in reactions of LAH with *Z*-2-chlorostilbene by the same authors.³⁷

Kornblum and coworkers have shown that the reactions of benzyl halides with salts of nitroparaffins give good yields of benzaldehyde whether the leaving group is chlorine, bromine or iodine.

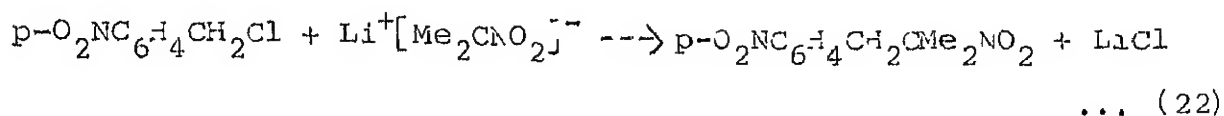


The nucleophilic anions of nitroparaffins are potentially ambident in character; being resonance-hybrids between such forms as (XII) and (XIII) given below. These might attack the substrate through the oxygen end or carbon end.



The latter type of reaction resulting in carbon alkylation may in certain cases become dominant, especially for the reactions involving attack on the o- or p-nitrobenzyl chlorides. In the example

represented by (eqn. 22), the yield of the carbon alkylation product



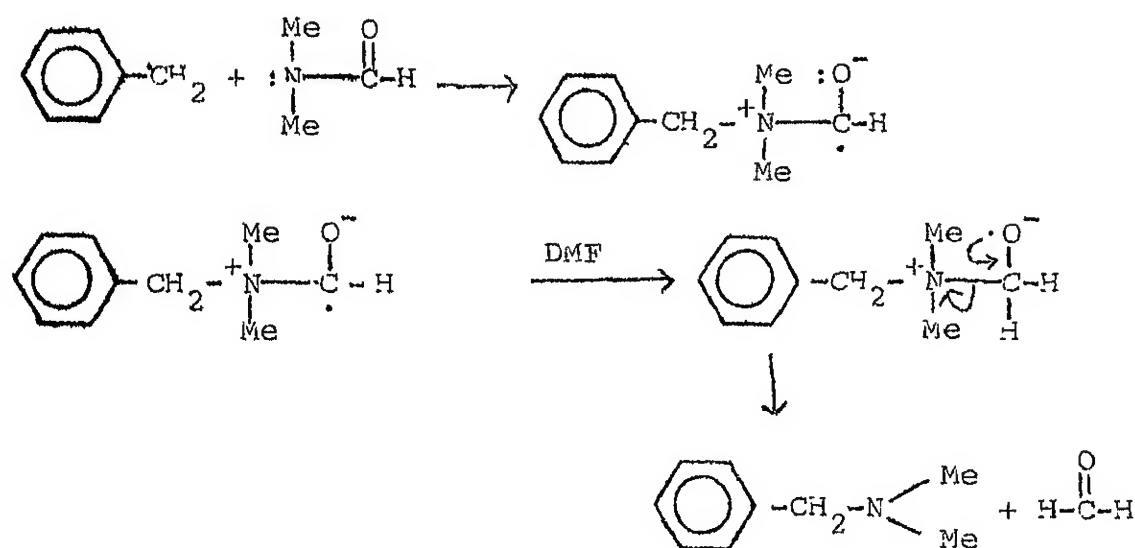
was 92 percent in dimethylformamide medium.

It was shown by using electron spin resonance spectroscopy that a solution of the lithium salt of 2-nitropropane in dimethylformamide converts other nitro-compounds into detectable amounts of their radical-anions by a single electron-transfer process. It was also observed that the inclusion of modest proportions of otherwise inert nitro-compounds in the medium in which p-nitrobenzyl chloride was reacting with the lithium salt of 2-nitropropane, diverted the product of reaction mainly to that of O-alkylation.

In the reduction of organic halides with metal ions or metal complexes, it is observed that variation in mechanistic pathways often occur with a change in the metal reagent; but the mechanistic differences are more due to the structure of the organic halide, than to the metal itself. However, only minor differences in energetics are responsible for separating the mechanisms and more extensive studies are required before any general mechanistic pattern can be developed with regard to the properties of the metal reductants.

Singh and Khurana³⁷ have examined the behaviour of Fe(II) and Co(II) compounds with benzylic halides, in DMF medium. Based on the product analysis, they have concluded that under conditions employed, DMF also intervenes in the reaction bringing about nucleophilic displacement of halogen by S_N2 type attack on 4-nitrobenzyl bromide and S_N1 type attack on other halides viz. 9-bromo-fluorene, benzhydryl chloride and trityl chloride, through its oxygen atom.

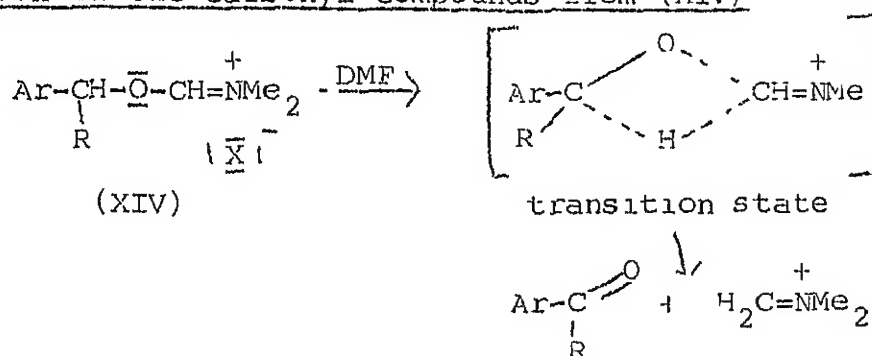
Dimethylamination takes place when the benzylic radicals reacts with DMF as shown below:



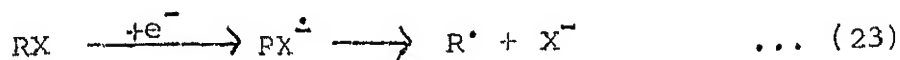
Cobalt(II) influences the course of these reactions by acting as an electron donor to the halide via outer sphere electron transfer process. Iron(II) behaves similarly with 4-nitrobenzyl bromide;

Scheme IV.11(contd.)

Formation of the carbonyl compounds from (XIV)



Electron transfer reduction of organic halides has been affected by powerful reagents such as alkali naphthalenes, lithium benzophenone ketyl and dicarbanions etc.^{6a,5c,8,43-46} to give radical anions which cleave to produce radicals (Eqn.23).



These radicals or anions formed by their reduction may serve as the immediate precursors of the products. However, it has been observed⁴⁵ that the reaction of the secondary and tertiary benzylic halides viz. benzhydryl chloride and trityl chloride occur via radical intermediates without any significant intervention of carbanions.

Since the possibilities of the existence of both radical and carbanionic intermediates in the sodium naphthalene reduction of purely alkyl halides and aryl halides have been indicated and also proved in some cases reported in the literature, we decided to examine the mechanistic details of the reactions of a few primary benzylic halides with sodium naphthalene.

IV.3 Results and Discussion

The roles of naphthalene radical-anion ($\text{Naph}^{\dot{-}}$) as a reducing agent (by donating an electron) and as a base have been reported in the literature.⁸⁻¹³

Our studies on four different primary benzylic halides show that in the case of p-nitrobenzyl bromide, $\text{Naph}^{\dot{-}}$ acts both as an electron donor and as a base in two simultaneously occurring pathways but reacts only as a reducing agent with benzyl chloride, 1-chloromethyl naphthalene and 9-chloromethyl anthracene. Each of these halides (0.01 mol) was reacted with an equimolar ratio of sodium naphthalene in THF at temperatures ranging from -10° to 0°C under pure, dry nitrogen atmosphere. The reactions were complete immediately after mixing the two reactants but were worked up after stirring for 15 min. The product distribution is given in Table IV.1.

TABLE IV.1: Product distribution in the reactions of primary benzylic halides ($\text{Ar-CH}_2\text{-X}$)^a with equimolar quantities of sodium naphthalene ($\text{Na}^+\text{Naph}^{\dot{-}}$) in THF under N_2 atmosphere (temp. range, -10° to 0°C)

Run	Ar-CH ₂ -X 0.01 mole	% yield of products				
		ArCH ₂ -CH ₂ Ar	ArCH ₃	ArCH=CHAr	1,4-Dihydro-naphthalene	Naphthalene
1	<u>1(1)</u> ^b	72	17	-	-	98
2	<u>1(11)</u> ^c	53	15	20	19	80

Table IV.1(contd.)

Table IV.1(contd.)

Run	Ar-CH ₂ -X 0.01 mole	% yield of products				
		ArCH ₂ -CH ₂ Ar	ArCH ₃	ArCH=CHAr	1,4-Dihydro- naphthalene	Naphtha- lene
3	<u>1(ii)</u> ^{c,d}	59	19	-	19	80
4	<u>1(iii)</u>	81	9	-	-	96
5	<u>1(iv)</u> ^b	80	9	-	-	98
6	<u>1(iv)</u> ^d	80	10	-	-	98

^aPrimary benzylic halides (Ar-CH₂-X) used were. 1(i): Ar=Phenyl, X=Cl; 1(ii): Ar=p-Nitrophenyl, X=Br; 1(iii): Ar=1-Naphthyl, X=Cl and 1(iv): Ar=9-Anthryl, X=Cl.

^bIn a separate run with the compound 1(i), benzyl carbanion was trapped; similarly, with compound 1(iv), 9-Anthrylmethyl carbanion was trapped.

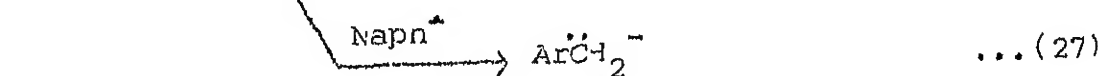
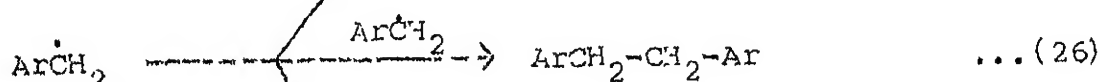
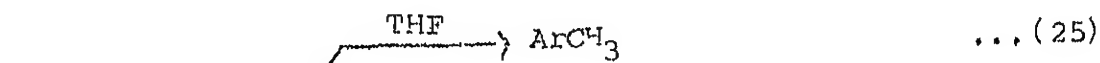
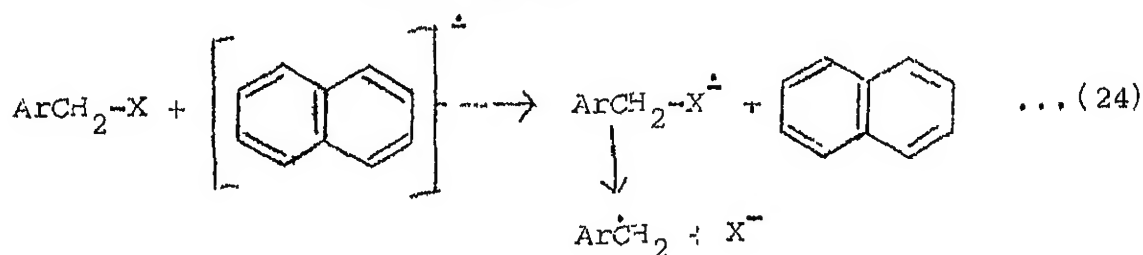
^cIn run 2, and run 3, 8% and 15% respectively of the starting material 1(ii) was recovered unchanged.

^dRun 3 and run 6 are the reactions of 1(ii) and 1(iv), respectively conducted in the presence of an excess of cyclohexene.

It is evident that in each of these reactions, the halide ArCH_2X gave a dimer corresponding to $\text{ArCH}_2\text{-CH}_2\text{Ar}$ as the major product. In addition, the denalogenated products corresponding to Ar-CH_3 were also obtained. In the case of p-nitrobenzyl bromide, 4,4'-dinitrostilbene (20%) was obtained along with 1,4-dihydronaphthalene (19%) in addition to other products mentioned above.

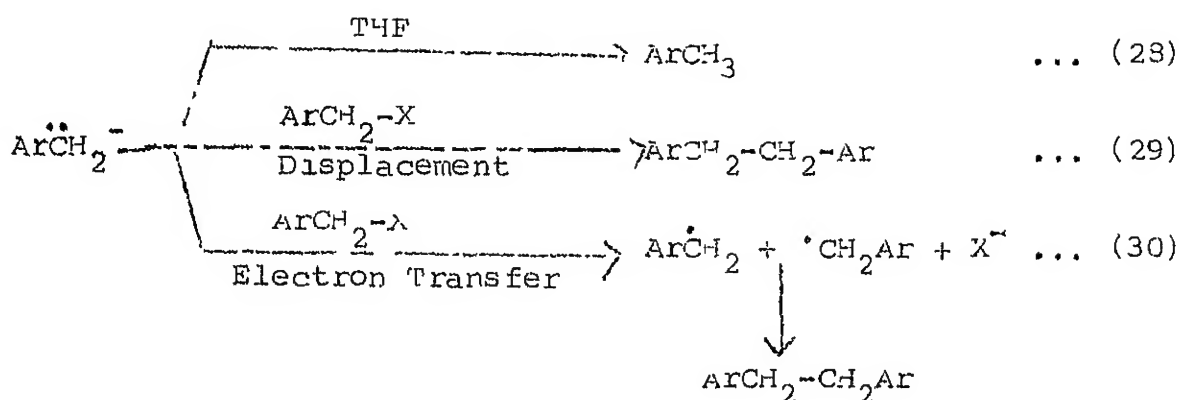
The conceivable pathways, taking the electron donating property of Naph^\bullet into account and leading to the formation of the usual products ArCH_3 and $\text{ArCH}_2\text{-CH}_2\text{Ar}$, may be visualized as illustrated in Scheme IV.12.

SCHEME IV.12



Scheme IV.12(contd.)

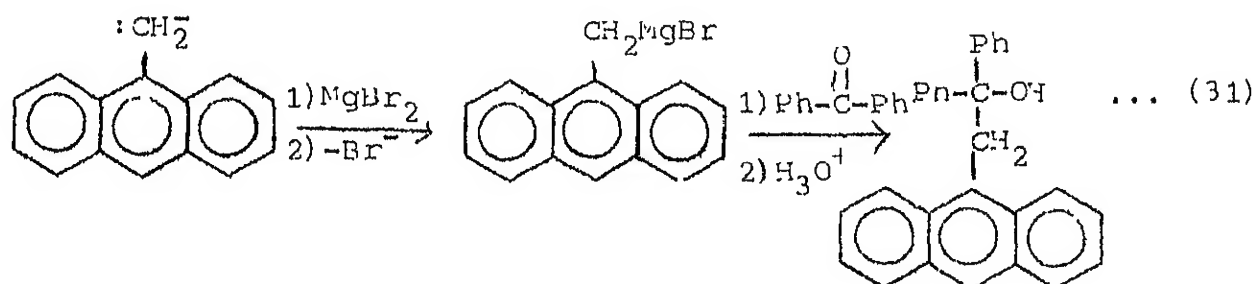
Scheme IV.12(contd.)



The first step involves an electron transfer from $\text{Naph}^{\dot{-}}$ to the organic halide and results in the formation of a free-radical via the radical-anion of the organic halide. This step has found general acceptance for a variety of organic halides. The radical $\text{Ar}\dot{\text{C}}\text{H}_2$ may either combine with sodium naphthalene to give alkylated naphthalene derivatives or abstract hydrogen atom from the solvent (THF) to give ArCH_3 (Eqn.25) or undergo coupling to produce the dimer $\text{ArCH}_2\text{CH}_2\text{Ar}$ (Eqn.26) or get reduced by $\text{Naph}^{\dot{-}}$ to the $\text{Ar}\ddot{\text{C}}\text{H}_2^-$ anion (Eqn.27).

Radicals formed in the presence of an aromatic radical-anion viz., $\text{Naph}^{\dot{-}}$ are expected to be reduced to carbanions faster than they can couple to form dimers.¹¹ Also, resonance stabilized benzylic radicals have been found to undergo coupling to dimers (via Eqn. 26) or reduction (via, Eqn. 27) faster than atom transfer from the solvent.⁴⁷ Thus, the relative efficiency of the steps accounting for the consumption of radicals $\text{Ar}\dot{\text{C}}\text{H}_2$ produced in eqn.24 is expected to be in the order of the eqns: 27 > 26 > 25.

Direct proof for the intervention of carbanions in the Naph[•] reductions of benzyl chloride and 9-chloromethylantracene was obtained by using anion trapping technique of Bank and Bank⁴⁸ as illustrated by means of the reaction of 9-chloromethylantracene in (Eqn. 31).



In a report¹¹ on the reaction between equimolar quantities of sodium naphthalene and benzoydryl trimethyl ammonium iodide in THF medium, diphenyl methyl carbanion intermediate has been proposed but no evidence in the support of the proposal has been recorded. Zeigler et al.⁴⁷ have reported the intermediacy of radicals in the reaction of benzoydryl chloride which is a secondary benzylic halide.

The anion trapping experiment attempted by us in the case of p-nitrobenzyl bromide could not lead us to any conclusion owing to the unexpected polymerization. Based on the results of Rakshys and our own results, it is reasonable to assume that p-nitrobenzyl carbanion might be easily formed in our experiment by the one electron reduction of the p-nitrobenzyl radical. This

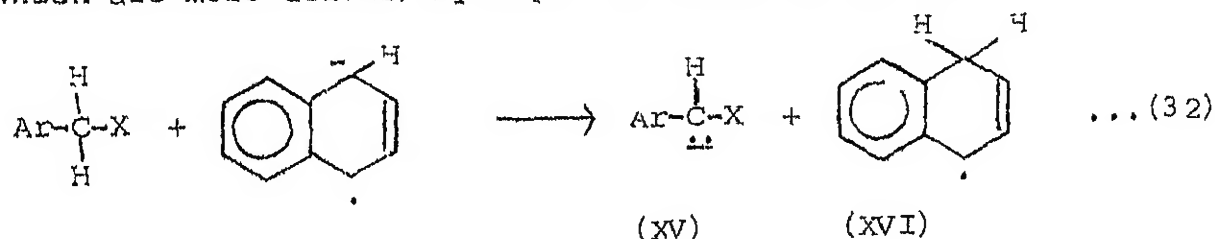
may also explain why in runs 2 and 3 small amounts of the starting halides were recovered unreacted inspite of the consumption of the entire quantities of the sodium naphthalene.

On their formation, carbanion $\text{Ar}\overset{\cdot\cdot}{\text{C}}\text{H}_2$ may abstract a proton¹⁵ (Eqn.28), undergo nucleophilic displacement reaction with the starting halide (Eqn.29) or reduce the halide after the disappearance of Naph^{\cdot} by an electron transfer process to produce radicals (Eqn.30) which may yield the final reduction products.

While the displacement process (Eqn.29) might be occurring to some extent when carbanions are produced, under our experimental conditions, oxidation of the carbanions by the halides to radicals (Eqn.30) constitutes a major component in the over-all mechanism.⁴⁷ Additional independent experimental evidence that electron transfer from carbanions to alkyl halides produces radicals which collapse to give the reduction products has been presented in the literature. Russell²⁶ identified radicals by ESR spectroscopy in the reactions of organolithium compounds with alkyl halides and Lawler and Ward⁴⁹ as well as Lapley and Landan⁵⁰ proved the presence of radicals employing chemically induced dynamic nuclear polarization technique (CIDNP). Garst and Barbas,^{5b} have concluded from their studies on α,ω -dihaloalkanes that cyclized or dimeric products have alkyl sodium precursors which via an electron transfer give diradicals before collapsing to the products (cf. Scheme IV.6). Our results³⁹ have also proved the intermediacy of radicals in the reactions of Grignard reagents with benzylic halides.

Although formation of dimer $\text{ArCH}_2\text{CH}_2\text{Ar}$ as well as the denalogenated product ArCH_3 takes place for the most part, via radicals derived from the anions (Eqn.30) in the reactions of benzyl chloride and 9-chloromethyl anthracene, there is evidence that small amounts of these products are derived from initially formed radicals (Eqn.24). Thus, while formation of $\text{ArCH}_2\text{CH}_2\text{Ar}$ and ArCH_3 is considerably suppressed by the anion trapping agent, these products are not completely eliminated under the conditions of anion trapping experiments.

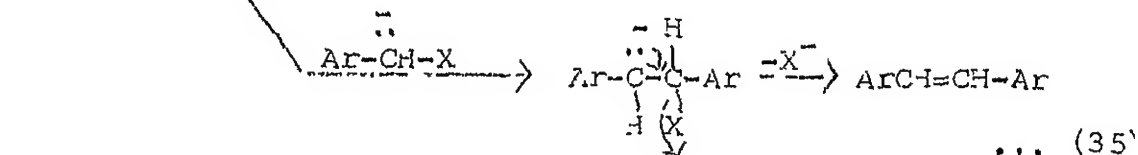
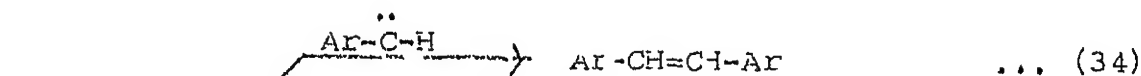
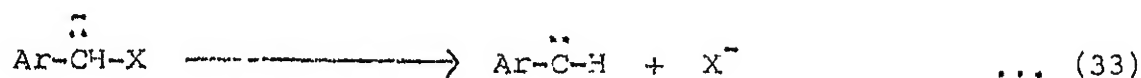
While nearly one equivalent of naphthalene was separated from the products of the reactions of benzyl chloride, 1-chloromethylnaphthalene and 9-chloroethylnaphthalene, as expected on the basis of $\text{Naph}^{\cdot-}$ acting exclusively as an electron donor, only 80 percent of the theoretical amount of naphthalene could be isolated from the reactions involving p-nitrobenzylbromide; the remaining quantity of naphthalene being isolated as 1,4-dihydronaphthalene. The formation of 1,4-dihydronaphthalene was coupled with the appearance of equivalent quantity of p,p'-dinitrostilbene. Existence of another important mechanistic component besides electron transfer reaction is, therefore, expected. This component of mechanism must initially involve abstraction of the α -protons (which are more acidic) by $\text{Naph}^{\cdot-}$ as shown in Eqn.32.



Radical (XVI) may abstract a hydrogen atom from THF to produce 1,4-dihydronaphthalene, while the α -halocarbanion (XV) may follow two conceivably different pathways as outlined in Schemes IV.13 and IV.14, respectively.

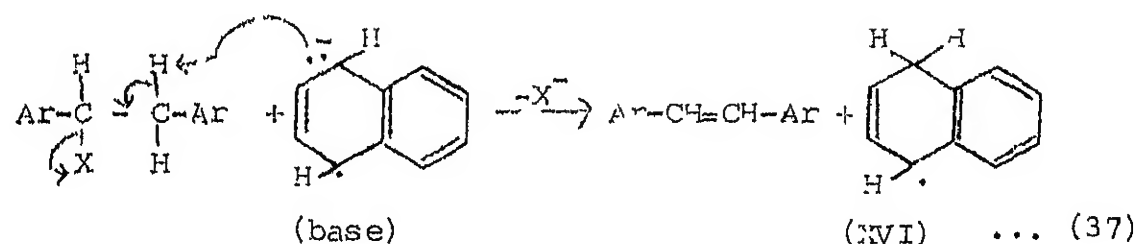
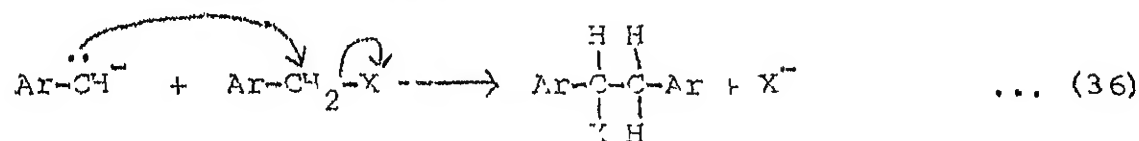
SCHEME IV.13

The carbene pathway



SCHEME IV.14

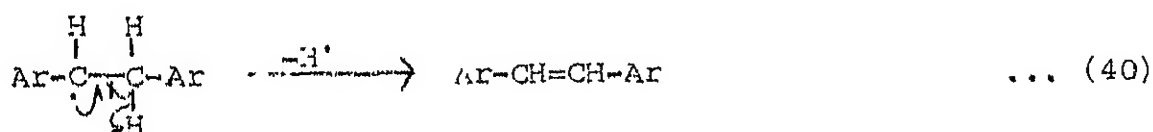
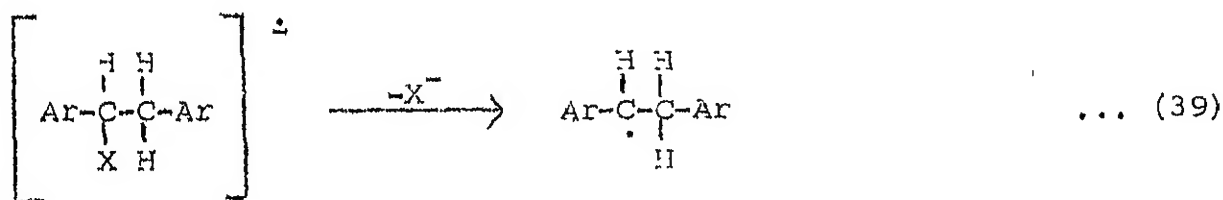
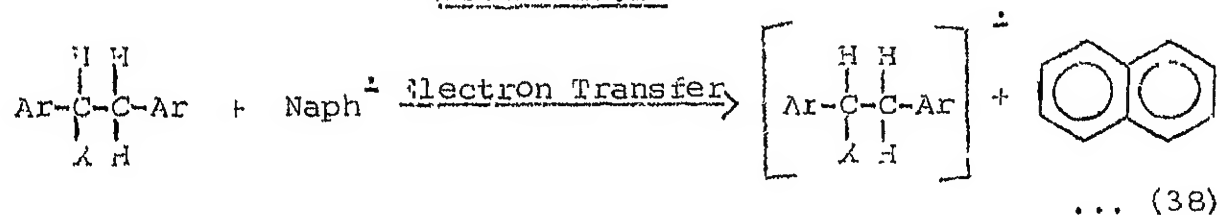
The bimolecular displacement pathway



In order to distinguish between the two possibilities visualized in Scheme IV.13 and IV.14, reactions of p-nitrobenzyl bromide was conducted in the presence of a ten-fold excess of cyclohexene, when the formation of p,p'-dinitrostilbene was completely suppressed. Another significant feature of this reaction in the presence of cyclonexene was that white unreacted halide was recovered to the extent of 15%, the yields of the corresponding reduction products ArC-I_3 and $\text{ArCH}_2\text{-CH}_2\text{Ar}$ registered an increase.

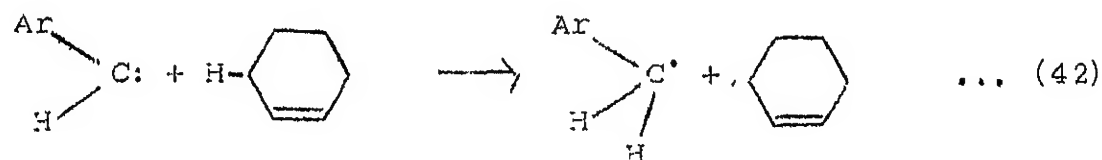
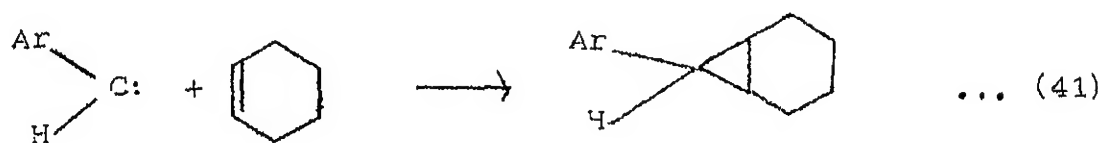
If the steps given in Scheme IV.14 were responsible for the formation of p,p'-dinitrostilbene, cyclohexene could do nothing to stop their formation unless it changed the role of Naph^\cdot (as a base) in (eqn.37) to that of an electron donating agent in which case, formation of p,p'-dinitrostilbene could be visualized as shown in scheme IV.15.

SCHEME IV.15



However, any action of cyclohexene towards changing the role of sodium naphthalene from that of a base to an electron donor leading to the reactions of Scheme IV.15 is highly unlikely. It is, therefore, concluded that the pathway illustrated in Scheme IV.13 represents the mechanism of the formation of p,p'-dinitrostilbene.

The intervention of cyclohexene in run 3 may take place either by carbene addition to the olefinic double bond (Eqn.41) or by means of a hydrogen atom transfer from cyclohexene to the carbene⁵¹ (Eqn.42).



While the reaction represented by (Eqn. 41) presumably removes a part of the carbene (in the form of cyclohexene addition product) which acted as precursor of the product ArCH=CHAr , the reaction illustrated by (Eqn. 42) produces more benzylic radicals which could dimerise to increase the yield of $\text{ArCH}_2\text{-CH}_2\text{-Ar}$ and also abstract hydrogen atoms from the medium adding to the yield of ArCH_3 . This is in accordance with our results. As no carbene intermediate is

involved in the reaction of 9-chloromethylnanthracene, cyclohexene is found not to exert any influence on the distribution of products in this case (compare run 6 with run 5). The mechanism followed in the reactions of benzyl chloride and 1-chloromethyl naphthalene is the same as that discussed for 9-chloromethylnanthracene.

IV,4 Experimental

All the melting points were recorded on a MEL-TEMP melting point apparatus. Infrared spectra were obtained on a Perkin-Elmer model 521 spectrophotometer. Known compounds were characterised by comparison of their IR spectra and TLC with those of the authentic samples, the mixed melting point technique and by elemental analysis. Literature melting points are taken from "Handbook of Chemistry and Physics", 50th edition, R.C. Weast (ed.) published by the Chemical Rubber Company, Cleveland, Ohio, unless specified otherwise. Column chromatography was done over activated silica-gel (100-200M). Silica-gel (asc-India) was used for TLC analysis.

Tetrahydrofuran (THF) was purified by keeping it over potassium hydroxide pellets overnight, refluxing over sodium for 5-6 h and then distilling over sodium followed by distillation over lithium aluminium hydride. It was stored in contact with freshly drawn sodium wire in a sealed (parafilm) flask and used within two days of drying.

Starting Materials

Naphthalene (BDH) was used after recrystallising twice from ethanol. Mg metal (BDH), benzyl chloride (E. Merck) 1,2-dibromoethane (BDH) and cyclohexene (E. Merck) were used after distillation. p-Nitrobenzyl bromide,⁵² 1-chloromethyl naphthalene⁵⁴ and 9-chloromethylanthracene,⁵³ were prepared by known methods. Benzophenone (Bush, England) was used as such.

Preparation of sodium naphthalene

In a three-necked round bottom flask mounted on a magnetic stirring base fitted with a device to pass pure, dry nitrogen and a dropping funnel and connected to a mercury trap, naphthalene (1.28g, 0.01 mol) dissolved in dry THF (30 ml) was taken. The contents of the flask were maintained at about 20°C. Pure dry nitrogen was flushed into the flask for a period of 30 min, with continuous stirring. Sodium metal (0.3g, ~0.013g-atom) cut into small pieces was added to it. The mixture was stirred rapidly first and then slowly after the reaction commenced. The progress of the reaction was measured from time to time by removal of a small sample of the reaction mixture and determination of its sodium content after dilution with alcohol, by titration with standard hydrochloric acid using metnyl red as indicator. The reaction was found to be complete in about 3 h.

Reaction of sodium naphthalene with benzyl chloride

A solution of benzyl chloride (1.1 ml, 0.01 mol) in THF (30 ml) taken in a 3-necked round bottom flask mounted over a magnetic stirring base and fitted with a pressure equalizing dropping funnel, a gas passing adapter and a mercury trap, was flushed with pure, dry nitrogen gas for 30 min. The contents were kept at a temperature ranging from -10° to 0°C .

A solution of sodium naphthalene (0.01 mol) in THF (30 ml) was slowly added through the dropping funnel under continuous magnetic stirring. The deep green color of sodium naphthalene was discharged immediately and a transient brown color appeared. After stirring the mixture for 15 min, it was poured into 100 ml water, acidified with hydrochloric acid and extracted with ether. The extract was washed with water, dried over anhydrous MgSO_4 overnight and concentrated by evaporation of the solvent.

GLC analysis of the ethereal extract using 10% SE-30 on Crom-P(85-100M) column of 2m length showed the presence of toluene (17%) and also indicated the presence of some bibenzyl as well as naphthalene.

The crude mixture of products obtained from the ethereal extract was then charged over an activated silica-gel column. The column was eluted with hexane when in addition to toluene

16.0%, naphthalene (1.22g, ~98%) was isolated. Continued elution with hexane-benzene (50:50) gave bibenzyl (0.91g, ~72%).

Compounds were identified by comparison of IR spectra with those of the authentic samples and mixed melting point.

Reaction of p-nitrobenzyl bromide with sodium naphthalene

A solution of p-nitrobenzyl bromide (2.16g, 0.01 mol) in THF (30 ml) taken in a 3-necked 250 ml RB flask mounted over a magnetic stirring base and fitted with a pressure equalizing dropping funnel, a gas passing adapter and a mercury trap, was flushed with pure, dry nitrogen gas for 30 min. The contents were kept at a temperature ranging from -10° to 0°C . A solution of sodium naphthalene (0.01 mol) in THF (30 ml) was slowly added through the dropping funnel under continuous magnetic stirring. The deep green color of the sodium naphthalene was discharged immediately and a transient deep brown color appeared. After stirring the mixture for 15 min, it was poured into 100 ml water, acidified with hydrochloric acid and extracted with ether. The extract was washed with water, and dried over anhydrous MgSO_4 . The solvent was evaporated to give a crude mixture of products. The crude mixture of products was shaken with petroleum-ether (bp. 60° - 80°) when part of it went into sodium. Chromatography of the soluble portion over activated silica-gel column using hexane, hexane-benzene (75:25), (50:50) and finally, benzene as eluants gave naphthalene (1.03g, ~ 80%); 1,4-dihydronaphthalene (0.229g, ~ 19%); p-nitrotoluene, m.p. found 51° , lit. 52°C

(0.205g, 15%), starting p-nitrobenzyl bromide (0.18g, ~8%), p,p'-dinitrobenzyl, m.p. found 178° , lit. $179-180^{\circ}$ (0.271g) and p,p'-dinitrostilbene, m.p. found $290-291^{\circ}$, lit. 293°C (0.268g, 20%). The petroleum-ether insoluble portion (0.477g) was identified as p,p'-dinitrobenzyl, the over all yield of which was 53%. Compounds were identified by comparison of IR spectra with those of the authentic samples, by mixed m.p., TLC and C & H analysis.

Reaction of 1-chloromethyl naphthalene with sodiumnaphthalene

The reaction of sodium naphthalene (0.01 mol) in THF (30 ml) with 1-chloromethyl naphthalene (1.765g, 0.01 mol) contained in THF (30 ml) was conducted exactly as described in the above experiments. A transient red color was formed after 15 min of the addition of sodium naphthalene. The reaction mixture was worked up in water acidified with hydrochloric acid and extracted with ether. The ethereal extract was separated, washed with water and dried over anhydrous MgSO_4 overnight. This was then filtered and concentrated.

GLC analysis of this concentrate indicated the presence of naphthalene.

Column chromatography of the crude mixture of products taken out of the ether extract, using petroleum ether (b.p. $60^{\circ}-80^{\circ}\text{C}$) gave naphthalene (1.20g, 96%). Further elution of the column with petroleum-ether:benzene (50:50) and benzene gave 1-methyl naphthalene (0.128g, ~9%) and 1,2-di-(1'-naphthyl)ethane (1.15g; ~81%),

respectively. Compounds were identified by comparison of IR spectra with those of the authentic samples, by mixed melting point, TLC and C, H analysis.

Reaction of 9-chloromethyl anthracene with sodium naphthalene

A solution of 9-chloromethyl anthracene (2.265g; 0.01 mol) in 30 ml dry THF was placed in a 250 ml RB flask mounted over a magnetic stirrer. The flask was fitted with a gas passing adapter, a pressure equalizing dropping funnel and a condenser connected to a mercury trap. Pure, dry nitrogen was passed into the flask for 30 min. A solution of sodium naphthalene (0.01 mol) prepared as described earlier was added through a dropping funnel. After 15 min the green color of sodium naphthalene turned to yellow, due to the precipitation of some yellow solid. This was filtered, washed with water and identified as 1,2-di-(9'-anthryl) ethane (m.p. -310° - -12° , lit. 312° C). The filtrate was acidified with hydrochloric acid and extracted with ether. The ethereal extract, after washing with water, drying over MgSO_4 (anhydrous) and evaporation of the solvent, gave a solid which was shaken vigorously with hexane. The hexane insoluble portion was filtered and identified as 1,2-di-(9'-anthryl)ethane. The material obtained after removal of hexane from the filtrate was chromatographed over silica-gel column using petroleum-ether (b.p. $60-80^{\circ}$ C) as eluant. The products thus isolated were; naphthalene (1.254g, $\sim 98\%$) and 9-methylanthracene (0.19g, $\sim 9\%$), m.p. 81° , lit. 81.5° . The total

yield of 1,2-di-(9'-anthryl)ethane obtained earlier was 1.50g (80%). The compounds were characterized by comparison of IR spectra, TLC mixed melting points and C & H analysis.

Reaction of sodium naphthalene with benzyl chloride in the presence of magnesium bromide

(a) Preparation of $MgBr_2$. Magnesium (0.48g, 0.02g atom) and THF (30 ml) were taken in a 3-necked RB flask which was equipped with a magnetic stirring device, a gas passing adapter, a condenser and a pressure equalizing dropping funnel. The system was flushed with pure, dry nitrogen gas and the contents of the flask kept under nitrogen atmosphere. 1,2-Dibromoethane (3.8g; 0.02 mol) contained in THF (30 ml) was slowly added to the contents of the RB flask with the help of the dropping funnel. Stirring was continued for an hour during which period $MgBr_2$ precipitated out.

(b) A solution of benzyl chloride (1.26g; 0.01 mol) in THF (30 ml) was added to the flask containing $MgBr_2$ prepared above. Thereafter, sodium naphthalene (0.01 mol) contained in 30 ml of THF was added with stirring, the contents of the flask being maintained below $0^{\circ}C$. After stirring the reaction mixture for 15 min, a solution of benzophenone (1.82g; 0.01 mol) in 15 ml of THF was added to the mixture and stirring continued at room temperature for 4 h. The mixture was then poured into 100 ml of water, acidified with hydrochloric acid and extracted with three 50 ml portions of ether.

The ethereal extract was washed with water and dried over MgSO_4 overnight. Evaporation of the ether gave a crude mixture which on chromatography over silica gel column using petroleum ether (b.p. $60^\circ\text{--}80^\circ$), petroleum-ether:benzene (50:50), benzene:ether (50:50) as eluants gave toluene ($\sim 6\%$), naphthalene (98%), bibenzyl (22%), benzophenone (50%) and a white solid identified as benzyl-diphenylcarbinol (1.0g, $\sim 47\%$), m.p. 89° , lit. $89\text{--}90^\circ$. The carbinol was conclusively characterised by C & H analysis and by comparison with an authentic sample prepared independently by the reaction of freshly prepared benzyl magnesium chloride (from benzyl chloride and magnesium) with benzophenone.

Reaction of sodium naphthalene with 4-nitrobenzyl bromide in the presence of magnesium bromide.

(a) Freshly precipitated MgBr_2 was prepared as in the above mentioned experiment using 0.02g-atom of magnesium and 0.02 mole of 1,2-dibromethane in a total of 60 ml of THF.

(b) A solution of p-nitrobenzyl bromide (2.16g; 0.01 mol) in THF (30 ml) was added to the flask containing MgBr_2 . Reaction was carried out with sodium naphthalene (0.01 mol) contained in THF (30 ml) as usual, below 0°C but the whole mixture turned into a tarry mass which could not be proceeded with further.

Reaction of 9-chloromethyl anthracene with sodium naphthalene in the presence of $MgBr_2$.

Magnesium bromide was prepared as described earlier using magnesium (0.48g; 0.02g-atom), THF (30 ml) and 1,2-dibromoethane (3.8g, 0.02 mol) in THF (30 ml). After, the addition of 9-chloromethyl anthracene (2.265g; 0.01 mol) dissolved in 30 ml of THF followed by sodium naphthalene (0.01 mol) in THF prepared earlier following the procedure described above, to the flask containing $MgBr_2$ and maintained below $0^{\circ}C$, stirring was continued for 15 min. Benzophenone (1.82g; 0.01 mol) dissolved in 15 ml of THF was added to the mixture and stirring continued for further 4 h at room temperature. The mixture was then poured into water (100 ml), acidified with hydrochloric acid and extracted with three 50 ml portions of ether. The ethereal layer was washed with water, dried over anhydrous $MgSO_4$ overnight and evaporated to remove the solvent. The resultant crude solid was washed with petroleum ether (60° - $80^{\circ}C$) when an insoluble and soluble portion were separated. The insoluble portion on washing with ether dissolved a small part of the petroleum-ether insoluble portion. The ether soluble portion on removal of solvent, yielded a white solid, m.p. $141^{\circ}C$ (1.22g) that corresponded to ($\sim 32\%$) of 9-anthryl methyl diphenyl carbinol. It was characterized further by C & H analysis.

The ether insoluble portion was identified as 1,2-di-(9'-anthryl)ethane, yield 0.4g, $\sim 20\%$. The petroleum ether soluble portion, on evaporation of the solvent, gave a solid which on

chromatography over silica-gel column using petroleum-ether (b.p. 60-80°), petroleum ether.benzene (50.50) and benzene as eluants gave naphthalene (1.27g, ~99%), 1-methyl naphthalene (0.09g, 4%), benzophenone (60%), and traces of 9-anthryl methyl diphenyl carbinol and 1,2-di-(9'-anthryl)ethane.

Reaction of sodium naphthalene with p-nitrobenzyl bromide in the presence of an excess of cyclonexene.

A solution of p-nitrobenzyl bromide (2.16g; 0.01 mol) in THF (30 ml) and cyclohexene (8.2g, 0.1 mol) were taken in a RB flask and sodium naphthalene solution (0.01 mol) contained in THF (30 ml) was added under the same conditions as described above for the reaction in the absence of cyclohexene. A transient deep brown color was observed. After workup in the usual manner, it was found that the products were: naphthalene (1.023g, ~80%); 1,4-dihydronaphthalene (0.23g, ~19%); p-nitrotoluene (0.26g, ~19%) and p,p'-dinitrobenzyl (0.802g, ~59%). Unreacted p-nitrobenzyl bromide (0.324g, ~15%) was recovered but no trace of p,p'-dinitrostilbene was found.

Reaction of sodium naphthalene with 9-chloromethylantracene in the presence of an excess of cyclohexene.

The preceding experiment was performed using the same quantities of reagents excepting that 9-chloromethylantracene (2.265g, 0.01 mol) was taken in place 4-nitrobenzyl bromide. The

familiar yellow coloration developed as the green color of sodium naphthalene vanished. On workup in the usual manner, the product distribution was found to be: naphthalene (1.254g, ~98%), 9-methylanthracene (0.2g, ~10%) and 1,2-di-(9'-anthryl)ethane (1.506g, ~80%) indicating almost no effect of the presence of cyclohexene on the product distribution.

IV.5 References

1. T.R. Tuttle and S.I. Weissman, J. Am. Chem. Soc., 80, 5342 (1958).
2. J.D. Young and N.L. Bauld, Tetranedron Lett., 2251 (1971).
3. K.W. Boddekar, G. Lang and U. Schidewolf, Angew. Chem. Int. Ed. Eng., 7, 954 (1968).
4. N.D. Scott, J.F. Walker and V.L. Hansley, J. Am. Chem. Soc., 58, 2442 (1936).
- 5.(a) J.F. Garst, P.W. Ayers and R.C. Lamb, J. Am. Chem. Soc., 88, 4260 (1966).
(b) J.F. Garst, J.T. Barbas and F.E. Barton II, J. Am. Chem. Soc., 90, 7159 (1968).
(c) J.F. Garst and J.T. Barbas, Tetranedron Lett., 3125 (1969).
- 6.(a) G.D. Sargent, J.N. Cron and S. Bank, J. Am. Chem. Soc., 88, 5363 (1966).
(b) G.D. Sargent and M.W. Browne, J. Am. Chem. Soc., 89, 2788 (1967).
(c) G.D. Sargent, J. Am. Chem. Soc., 90, 7161 (1968).
(d) T.D. Walsh and R. Dabestani, J. Org. Chem., 46, 1222 (1981).
7. D.B. Leollic, R.L. Thorne and G. Weiss, J. Org. Chem., 36, 2186 (1971).
8. J.F. Garst, Acc. Chem. Res., 4, 400 (1971) and references therein.
9. N.L. Holy, Chem. Rev., 74, 243 (1974) and reference therein.
10. J.F. Garst and F.E. Barton, II, J. Am. Chem. Soc., 96, 523 (1974).

11. I. Angres and H.G. Zeiger, J. Org. Chem., 39, 1013 (1974)
12. P.R. Singh and R. Kumar, Indian J. Chem., 11, 692 (1973).
13. Pamesh Kumar, Ph.D. Thesis, Indian Institute of Technology, Kanpur, India, 1973.
14. T.C. Cheng, L. Headley and A.F. Halasa, J. Am. Chem. Soc., 93, 1502 (1971).
15. G.D. Sargent, Tetrahedron Lett., 3279 (1971).
16. W. Adam and J. Arce, J. Org. Chem., 37, 507 (1972).
17. S. Bank and J.F. Bank, Tetrahedron Lett., 4581 (1971).
18. G.D. Sargent, C.M. Tatum and S.M. Kastner, J. Am. Chem. Soc., 94, 7174 (1972).
19. J.G. Smith and I. Ho, J. Org. Chem., 37, 4260 (1972).
20. J.G. Smith and I. Ho, J. Org. Chem., 38, 3601 (1973).
21. D.J. Morantz and E. Warhurst, Trans. Faraday Soc., 51, 1375 (1955).
22. H.V. Carter, B.J. McClelland and E. Warhurst, Trans. Faraday Soc., 56, 343 (1960).
23. R.C. Lamb, P.W. Ayers and M.K. Toney, J. Am. Chem. Soc., 85, 3483 (1963).
24. (a) J.F. Garst and J.T. Barbas, J. Am. Chem. Soc., 91, 3385 (1969).
 (b) J.F. Garst and J.T. Barbas, J. Am. Chem. Soc., 96, 3239 (1974).
 (c) H.G. Zeiger, I. Angres and D. Mathison, J. Am. Chem. Soc., 98, 2580 (1976).
25. D. Bryce-Smith, J. Chem. Soc., 1603 (1956); Bull. Soc. Chim. Fr., 1418 (1968).
26. G.A. Russell and D.W. Lamson, J. Am. Chem. Soc., 91, 3967 (1969).

27. H. Fiscner, J. Phys. Chem., 73, 3834 (1969).
28. "Organometallic Mechanisms and Catalysis", J.K. Kochi, Academic Press, New York, 1978, pp. 246-368.
29. (a) G. Bocne, D.R. Schneider and H. Winternmayer, J. Am. Chem. Soc., 102, 5697 (1981).
(b) P.K. Freeman and L.L. Hutchinson, J. Org. Chem., 45, 3191 (1980).
30. F.W.G. Fearson and J.C. Yong, J. Chem. Soc. (13), 272 (1971).
31. J.F. Garst and J.T. Barbas, J. Am. Chem. Soc., 96, 3247 (1974).
32. J.W. Raksnys, Jr., Tetranedron Lett., 4745 (1971).
33. C.G. Scouten, F.T. Barton, Jr., J.R. Burgess, P.R. Story and G.F. Garst, Chem. Comm., 78 (1969).
34. R.N. McDonald and D.G. Frichey, J. Am. Chem. Soc., 90, 5315 (1968).
35. E. Vogel, H. Kiefer and W.R. Roth, Angew. Chemie. Int. Ed. Eng., 3, 442 (1964).
36. J.S. McKennis, L. Brener, J.R. Schweiger and R. Pettit, Chem. Comm., 365 (1972).
37. J.M. Khurana, Ph.D. Thesis, Indian Institute of Technology, Kanpur, 1981 August.
38. W.G. Hodgson, A. Neaves and C.G. Venier, J. Org. Chem., 31, 3561 (1966).
39. P.R. Singh, S.R. Tayal and Alok Nigam, J. Organometal. Chem., 42, C9 (1972).
40. Sung-Kee Chung, J. Org. Chem., 45, 3513 (1980).
41. Sung-Kee Chung and Fu-fan Chung, Tetranedron Lett., 2473 (1979).
42. S.C. Ashby and A.B. Goel, Tetranedron Lett., 1879 (1981).

43. J.F. Garst, in "Free Radicals", J.K. Kochi(Ed), Vol I, pp.503, Wiley (Interscience), New York, 1973.
44. J.F. Garst and C.D. Smith, J. Am. Chem. Soc., 98, 1520 (1976).
45. A. Nigam, Ph.D. Thesis, Indian Institute of Technology, Kanpur (India), 1975.
46. T.D. Walsh and R. Dobestani, J. Org. Chem., 46, 1222 (1981).
47. H.E. Zieger, J. Angres and L. Maresca, J. Amer. Chem. Soc., 95, 8201 (1973).
48. S. Bank and J.F. Bank, Tetrahedron Lett., 4533 (1969).
49. H.R. Ward, R.G. Lawler and R.A. Cooper, J. Am. Chem. Soc., 91, 747 (1969).
50. A.R. Lepley and R.L. Landan, J. Am. Chem. Soc., 91, 748 (1969)
51. Carbenes, both triplet (which would be expected because these are diradicals) and singlet. Royn, J, Am. Chem. Soc., 93, 1527, 4935 (1971) can abstract hydrogen atoms to give free radicals.
52. G.H. Coleman and G.E. Honeywell, A.H. Blatt(Ed.), 'Org. Syn'. Coll. Vol.II, 1959, pp. 443.
53. F.H.C. Stewart, Aust. J. Chem., 13, 478 (1960).
54. Lock, Walter, Ber., 75, 1158 (1942).

CHAPTER V

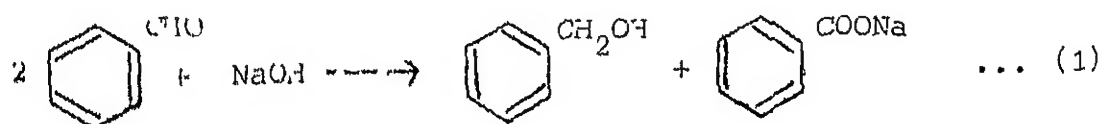
A NEW MECHANISM OF CANNIZZARO REACTION

V.1 Abstract

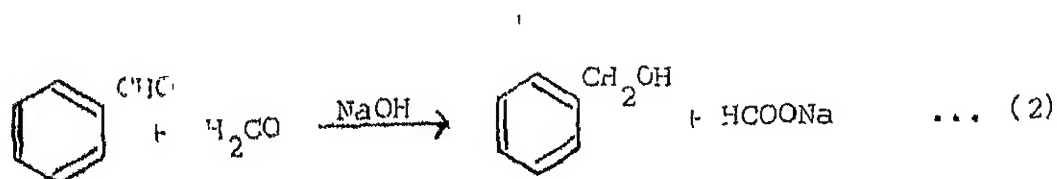
Reactions of four aromatic aldehydes viz. benzaldehyde, p-chlorobenzaldehyde, p-bromobenzaldehyde and p-nitrobenzaldehyde in the presence of an excess of sodium hydroxide at room temperature (30°C) in THF/HMPA (9:1) have been found to give the Cannizzaro products. Benzaldehyde reacts slower than other aldehydes and also yields benzyl benzoate as an additional product. On the basis of available facts, a hydride transfer mechanism for the cannizzaro reaction seems irrational. An electron transfer mechanism with free radical intermediates has been proposed which appears to satisfactorily account for all the observations. Further studies are being conducted for verification of this mechanism.

V.2 Introduction

The reaction in which two aldehyde groups, under the influence of a strong base, are transformed into the corresponding hydroxyl and carboxyl functions, existing separately or in combination as an ester, is termed the Cannizzaro reaction.¹ The reaction consists of dismutation of two similar aldehyde groups into corresponding alcohol and carboxylic acid salt by means of aqueous or alcoholic alkali. For example, benzaldehyde is converted into equimolar mixture of benzyl alcohol and sodium benzoate in the presence of sodiumhydroxide as shown in Eqn.1.



Dismutation of the same type, but involving two unlike aldehyde molecules, is classified as "Crossed Cannizzaro Reaction". For example:

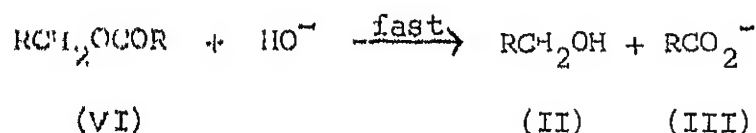
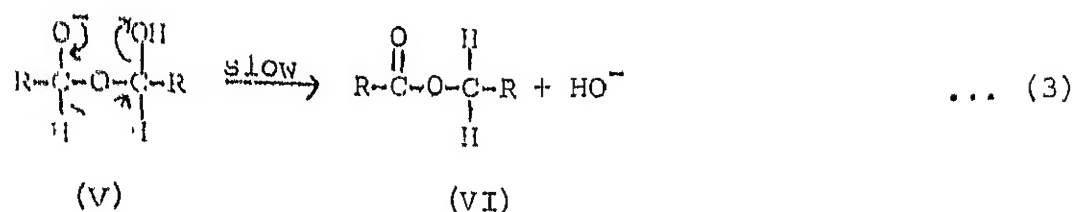
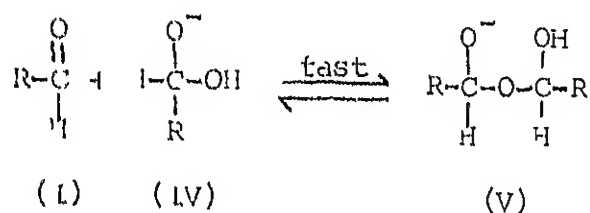
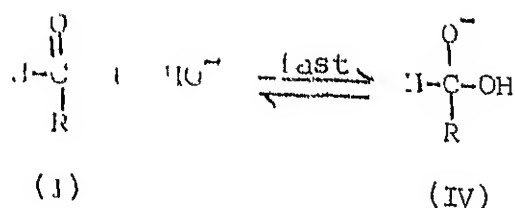


Only the aromatic and aliphatic aldehydes which have no α -hydrogen give the Cannizzaro reaction. Aldehydes with an α -hydrogen do not give this reaction because when such compounds are treated with a base, the aldol condensation is much faster.

The Cannizzaro reaction has been described as a disproportionation of aldehydes into an equimolar mixture of the corresponding alcohols and acids, and is normally carried out under strongly basic conditions. This was considered to be one of the most important synthetic reactions of organic chemistry involving reduction of aldehydes prior to the discovery of lithium aluminium hydride in 1946.

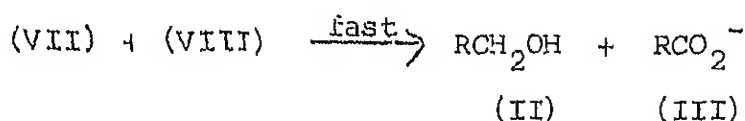
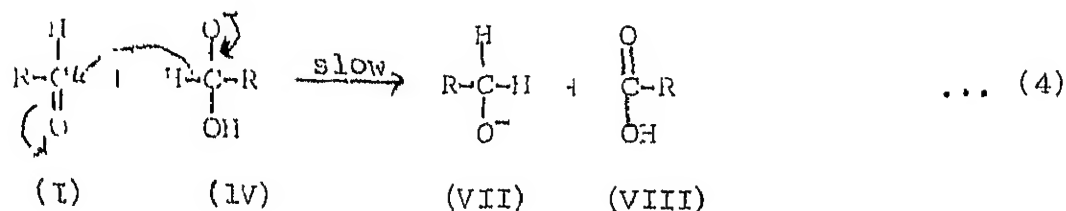
Cannizzaro² discovered that benzaldehyde rapidly solidifies when shaken with an excess of a strong solution of sodium hydroxide (Eqn.1). A number of workers have found that if water is excluded in this reaction, benzyl benzoate is the primary product. Claisen³ added sodium methoxide to benzaldehyde and obtained a mixture of benzyl benzoate and methyl benzoate; and he also found that a small amount of sodium benzoate ($C_6H_5CH_2CO_2Na$) was capable of converting a large quantity of benzaldehyde directly into benzyl benzoate. Kohn and Tranton⁴ heated benzaldehyde and were able to isolate some benzyl benzoate from the mixture. Tischtschenko⁵ obtained esters of benzoic acid when he treated benzaldehyde with aluminium alcoholates.

Several mechanisms have been proposed for the homogenous Cannizzaro reaction. The first^{1,6-8} has (Eqn.3) as its rate determining step. (R=phenyl).



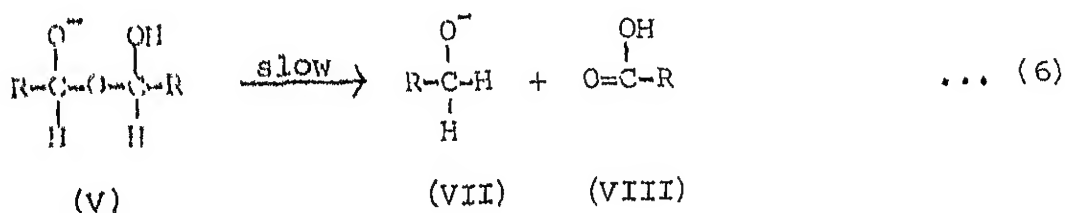
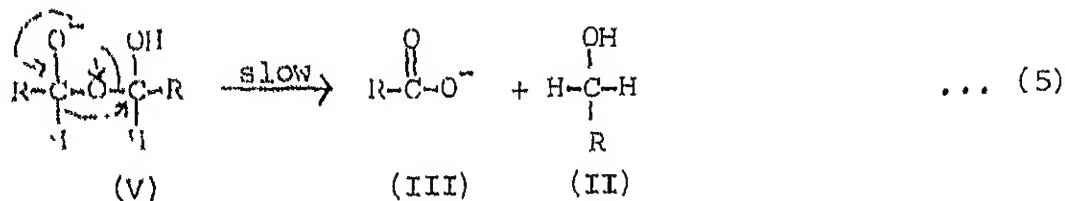
This mechanism involves formation of (VI) as an intermediate. Since ¹⁸O exchange between water and (I) is much faster than the Cannizzaro reaction⁹, in which exchange occurs even at 25°C with no base added, the rate-determining step cannot be formation of adduct (IV) or the mechanistically similar formation of adduct (V), but it might be rearrangement (Eqn.3) of (V) to (VI).

A second mechanism¹⁰ involves (Eqn.4) with a prior equilibrium for (IV) as in mechanism I.



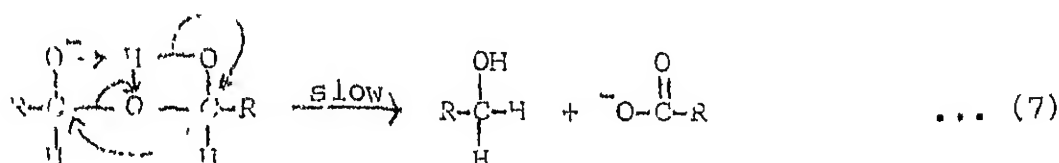
this mechanism involves a rate-determining intermolecular hydride shift, followed by a fast proton transfer.

rearrangements of (V) that do not lead to the formation of (VI) have also been proposed¹¹ as shown below.



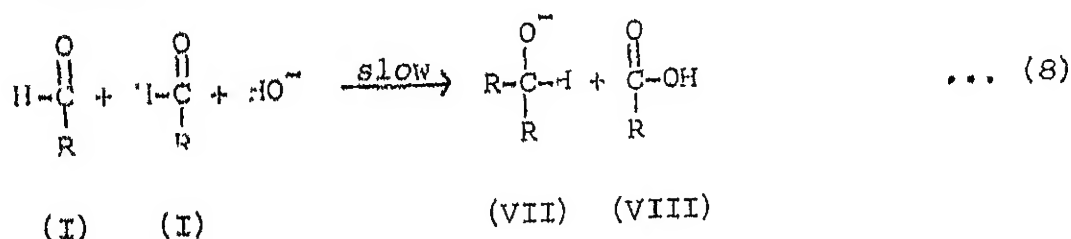
In (Eqn. 5), the stable products (III) and (II) are formed directly in the rate-determining step, while in (Eqn. 6), a fast proton transfer occurs after the rearrangement to form the stable product.

Another rearrangement of (V), involves a proton transfer in the slow step to produce the stable products as shown in (Eqn.7).



Thus we see that in any solution of (IV) and (I), there will be some (V) in equilibrium. In Eqns.3,5,6 and 7, it is considered that (V), inspite of its low concentration, reacts at a faster rate than more abundant reactants (I) and (IV) because (V) holds the migrating hydrogen in a favourable position for an intramolecular rearrangement. In Eqn. 4, the necessary intermolecular hydride transfer cannot occur unless (I) and (IV) happen to collide with precisely correct orientations.

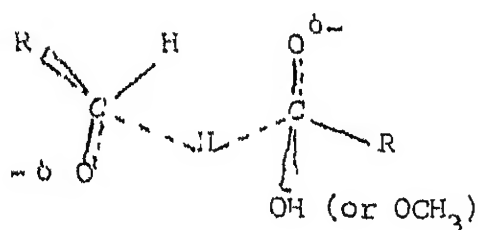
Mechanisms that are still simple in the sense of by passing (IV) can be proposed. Eqn.8 provides an example of such type. Here, (IV) is a reversibly formed by-product in equilibrium with the reactants but not an intermediate along the main reaction path.



Bimolecular mechanisms¹² have been demonstrated in various systems, experimentally. General arguments against termolecular

mechanisms are not valid at high concentrations ordinarily used in the Cannizzaro reaction.¹³ Mechanisms represented by (Eqns. 8 and 4) could have the same transition state.

Most of the mechanisms proposed above have been disproved¹⁴ and only steps proposed in (Eqns. 4 and 8) have been shown to be the allowed reactions.¹⁰ A reasonable structure for the transition state in (Eqns. 4 and 8) is as illustrated by (IX). The C-H-C bond may be bent.¹⁵ The carbonyl oxygen of one or those of both

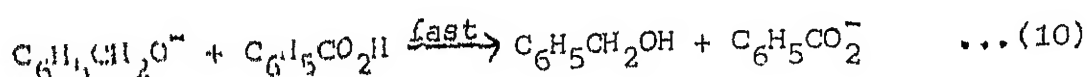
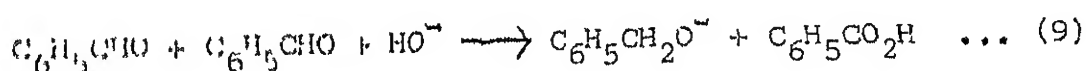


(IX)

aldehydes are likely to be polarized by hydrogen bonding to water or alcohol or solvent molecules and reasons have been given¹⁶ for proving that such protons have normal bonds with normal zero-point energy at the transition state.

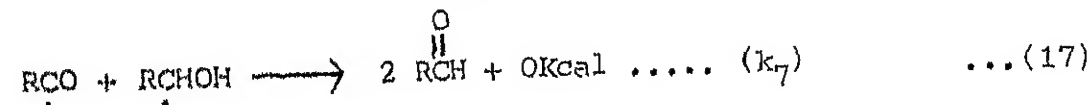
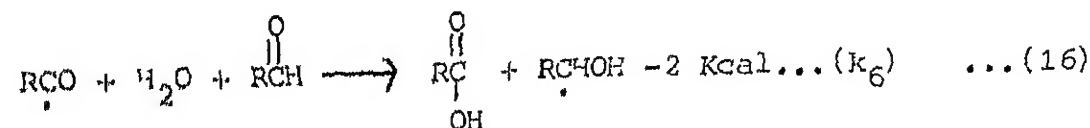
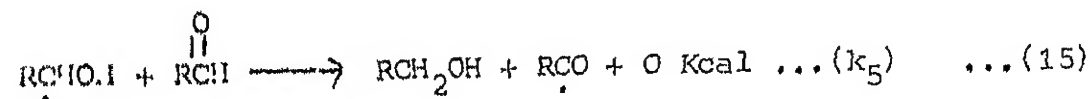
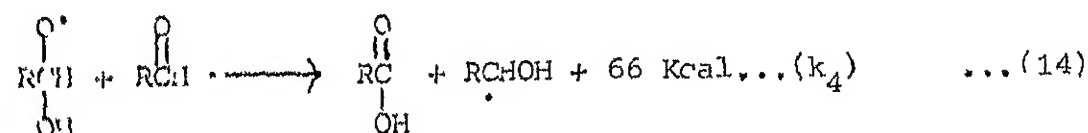
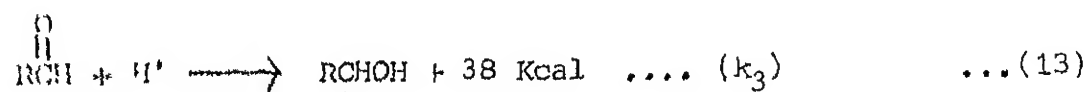
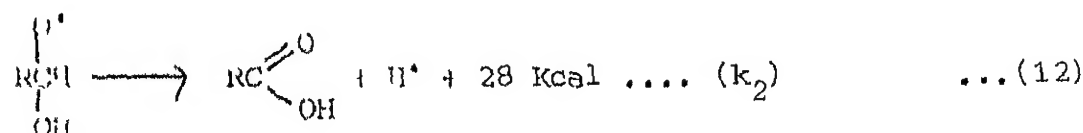
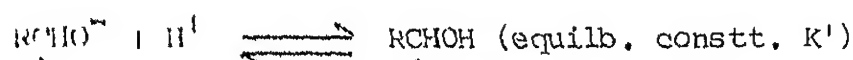
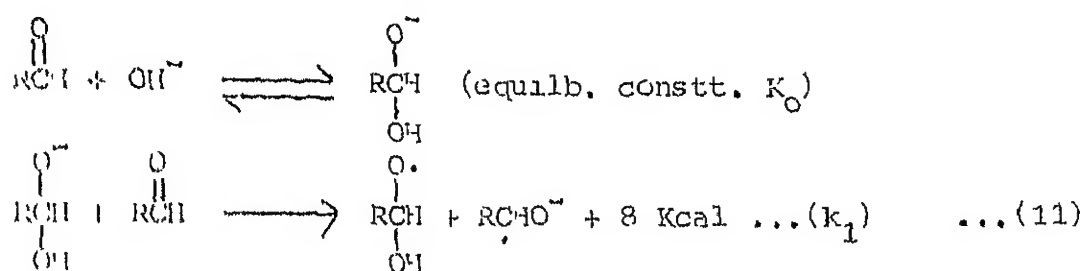
Reduction of benzaldehyde by methoxide ion in aqueous methanol has been studied¹⁷ and the products from C_6H_5CHO in CH_3OH , CD_3OD and CD_3OH solutions have indicated that the side reactions responsible for hydrogen exchanges and adding to the yield of benzyl alcohol are (1) bimolecular hydride transfer to benzaldehyde, from methoxide ion, (2) a nearly equal amount of crossed Cannizzaro reaction from the resulting formaldehyde, (3) a smaller

amount of hydride transfer to benzaldehyde from the resulting sodium formate leading to sodium carbonate, and (4) a less frequent combination of the two i.e. benzaldehyde plus methoxide ion leading to benzaldehyde dimethyl acetal. Decreasing the initial concentration of C_6H_5CHO decreases the relative contributions of the termolecular reactions and causes the bimolecular hydride transfer to become the dominant reaction. C.G. Swain et al.¹⁷ studied the mechanism of the Cannizzaro reaction of benzaldehyde in aqueous methanol, rather than with hydroxide ion in water, aqueous dioxane, or any other solvents. They were able to exclude rigorously five mechanisms for the main reaction (three from the literature and two others considered plausible ones) not eliminated by the previously reported experimental works, and were left with yet another hydride transfer to benzaldehyde, this time from the combination of benzaldehyde and hydroxide ion (Eqn.9).



In 1931 Haber and Willstatter³⁸ proposed a chain mechanism for the Cannizzaro reaction, but this suggestion was more or less disregarded, and was thought to be inconsistent with the known facts. The important fact in the Haber-Willstatter theory lies in the introduction of the radicals $\dot{R}CO$ and $\dot{R}CHOH$, both formed

from the aldehyde molecule (RCHO) through a (univalent) oxidation or reduction. The mechanism proposed by these authors was as follows:



Only comparatively simple elementary processes (electron or hydrogen atom transfers) are involved in the above scheme of

reactions, for all of which the energy requirements are fulfilled.^{18, 19}

Experimental evidence is also available for the individual reaction steps, and the occurrence of the free radicals assumed in the above mechanism.²⁰

Low²¹ observed that on treating formaldehyde with an oxidising agent (Ag_2O , Cu_2O) in alkaline solution, formic acid and molecular hydrogen are formed, the amount of formic acid being greater than that which corresponds to the oxygen in the oxide. The same reaction takes place with many other oxidising agents, e.g., CuO ²², $\text{K}_4\text{Fe}(\text{CN})_6$ ²², $\text{K}_2\text{S}_2\text{O}_8$ ²² and H_2O_2 .^{23a,b}

Miller²² showed that on electrolysing alkaline solutions of formaldehyde, acetaldehyde or benzaldehyde, each farad produces on the anode (Ag or Cu) one equivalent of hydrogen and one molecule of the corresponding acid. Thus, it shows that if an oxidising agent is present in considerable quantity, the H atoms formed appear mainly as molecular hydrogen.

In view of the above facts, it was confirmed that under suitable conditions oxidising agents actually accelerate Cannizzaro reaction. This has been found to be the case with ferrate, silver oxide, and benzoyl peroxide. Moreover, Kharasch²⁴ and Urushibara and Takebayashi²⁵ found that the peroxides, formed from the molecular oxygen and the aldehyde, have a considerable accelerating effect, and that under certain conditions, the Cannizzaro reaction

of benzaldehyde is completely inhibited in the absence of any peroxide. They have also found that $\text{Fe}(\text{OH})_2$ or $\text{Mn}(\text{OH})_2$ inhibit the Cannizzaro reaction of benzaldehyde probably on account of their reducing action on the peroxides.

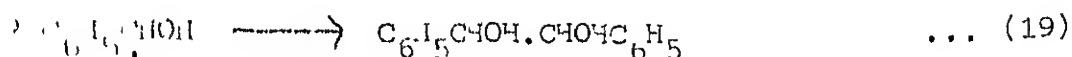
Delepine and Horeau²⁶ have observed formation of H_2 gas on treating formaldehyde in alkaline solution with platinum. In the presence of a good hydrogenation catalyst (e.g. Raney-Ni) the Cannizzaro reaction occurs, whereas in the presence of a poor hydrogenation catalyst, hydrogen gas is evolved.

It is seen that the radical $\text{R}\dot{\text{C}}\text{HOH}$ not only acts as an intermediate but is also capable of starting the Cannizzaro reaction. This is proved by the following facts: when Na-amalgam is allowed to react with benzaldehyde (in the absence of oxygen) Na-benzoate and benzyl benzoate are obtained after decomposition with water. The addition of Na to the aldehyde results in the formation of a ketyl radical:

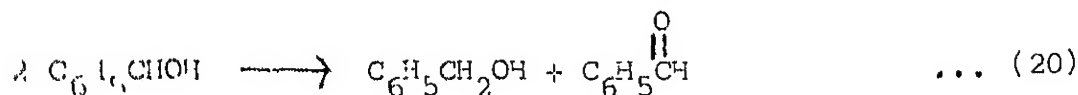


This radical is decomposed by water to give $\text{C}_6\text{H}_5\dot{\text{C}}\text{HOH}$ radical.

After decomposition with water, the products of the reaction of Mg-amalgam on benzaldehyde,⁴² are found to be Mg-benzoate, benzylbenzoate and hydrobenzoin.



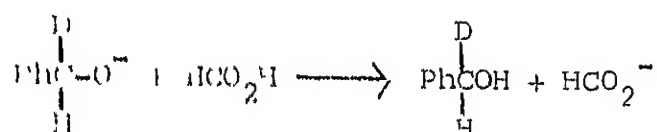
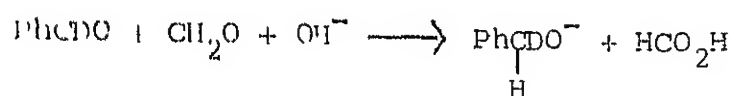
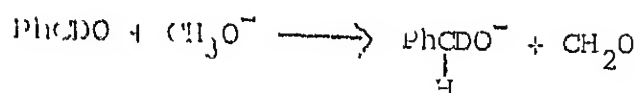
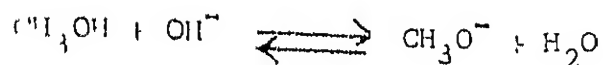
Hydrogen atom transfer between the radicals yield,



In the absence of an excess of benzaldehyde (i.e. if dilute solutions of the aldehyde in ether or benzene are treated with Na), the Cannizzaro reaction did not occur to any appreciable extent, and mainly hydrobenzoin was formed.

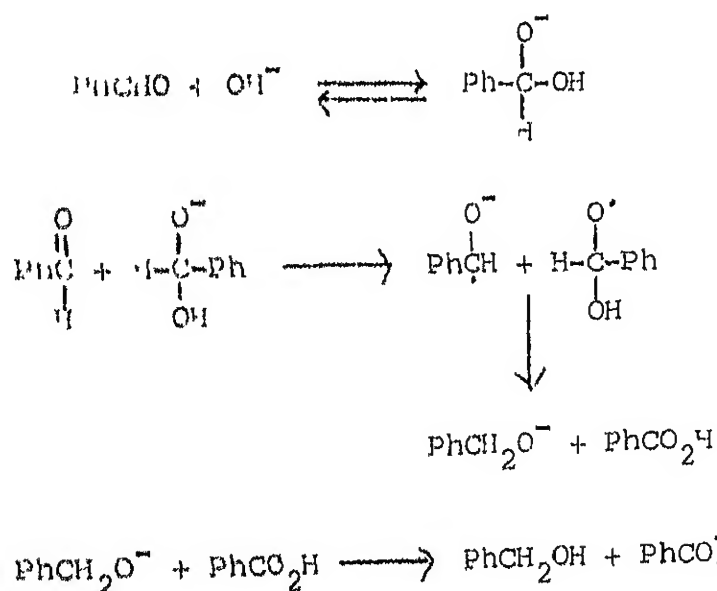
The Cannizzaro reaction of [α - ^2H]benzaldehyde in alkaline aqueous dioxan or dioxane alone was studied by Sung-Kee Chung²⁷ who found out that apart from the normal product [α - $^2\text{H}_2$] benzyl alcohol, substantial amounts of [α - ^2H] benzyl alcohol was formed, thereby, suggesting a possible partial involvement of radical intermediates.

In contrast to the previous observation that the alcohol obtained from the Cannizzaro reaction of benzaldehyde in D_2O ²⁸ did not contain any carbon-bound deuterium, Swain et al.¹² reported that benzyl alcohol from the reaction of [α - ^2H] benzaldehyde and NaOH in aqueous methanol at 100°C included a substantial percentage of the [α - ^2H] alcohol along with the expected [α - $^2\text{H}_2$] alcohol. This was rationalized in terms of oxidation of the methoxide ion and the subsequent cross Cannizzaro reaction between formaldehyde and [α - ^2H] benzaldehyde as shown below:

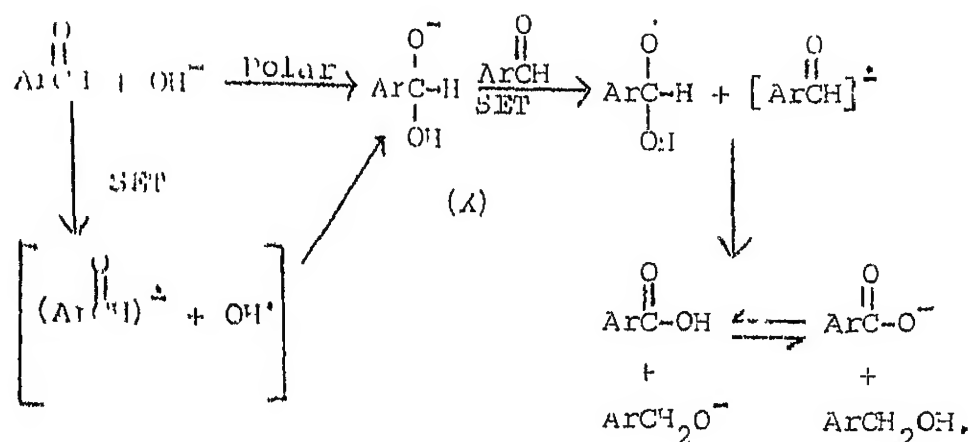


In view of the observation that a typical hydride donor reagent, LiAlH_4 could behave as an electron as well as a hydrogen atom donor²⁰, it was considered that the hydrogen isotope incorporation into benzyl alcohol from $\text{H}_2\text{O}-\text{CH}_3\text{OH}$ in the Cannizzaro reaction might be due to the intervention of radical intermediates.

The mechanism proposed is as follows:

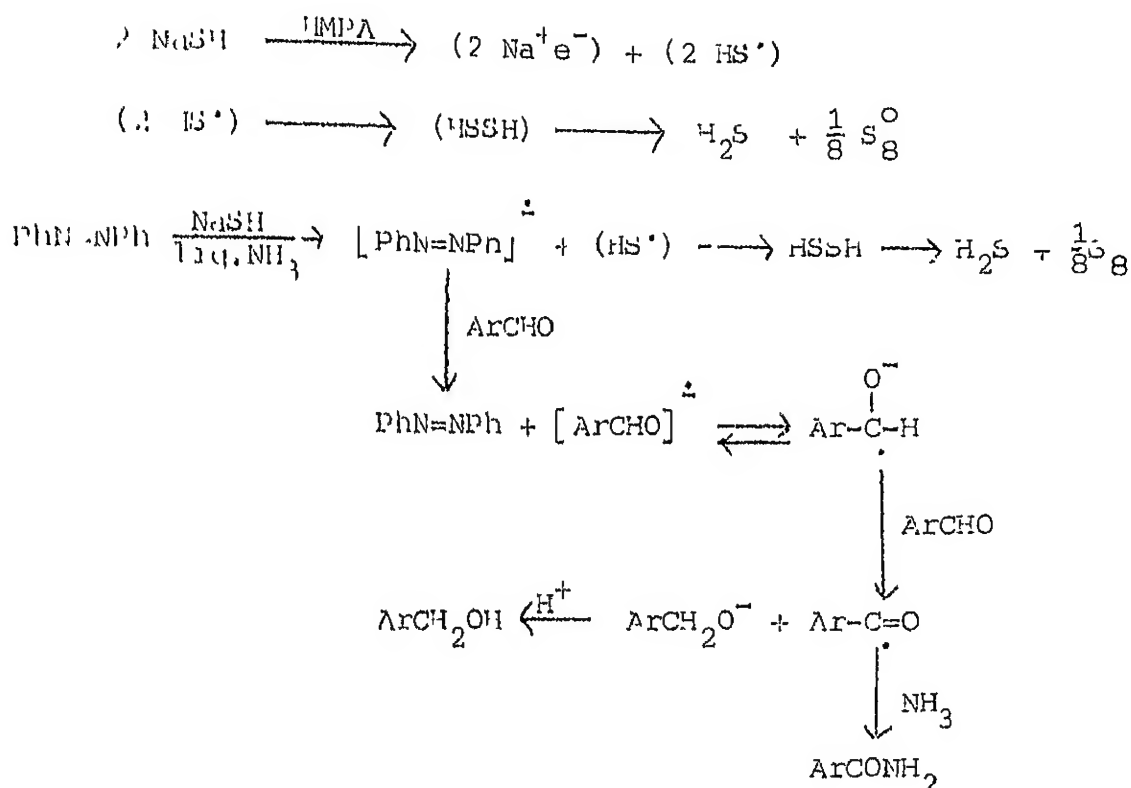


G.C. Ashby et al.³⁰ have studied the Cannizzaro reaction by EPR spectroscopy and have obtained evidence for the existence of paramagnetic species in solution. The mechanism presented by them is as follows:



It can be seen that intermediate (X) can be formed by either of the two pathways. Independent evidence that OH^- is a good single electron donor proves that SET pathway is possible.

Tsujl Takikawa, et al. have recently studied the reaction of substituted benzaldehyde with sodium hydrogen sulfide or sodium sulfide in liquid ammonia and proposed a mechanism which involves benzaldehyde radical anion. Since these reactions proceed only in the presence of an additive such as nitrobenzene, nitrosobenzene or azobenzene which are good electron acceptors, a reaction mechanism involving a single electron transfer is considered plausible.



Though Cannizzaro reaction is, ordinarily, restricted to aldehydes that are devoid of an α -hydrogen, other aldehydes^{36,37} may also undergo this reaction, if the α -position is sufficiently hindered to inhibit the competing aldol-type condensation under those conditions. Thus, isolongifoldehyde was intercepted by a Cannizzaro-type reaction to give the corresponding alcohol and acid,

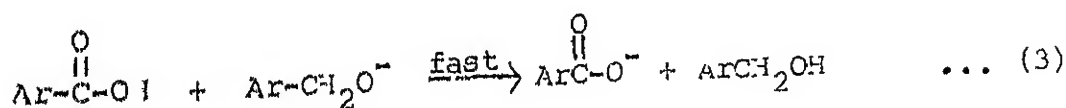
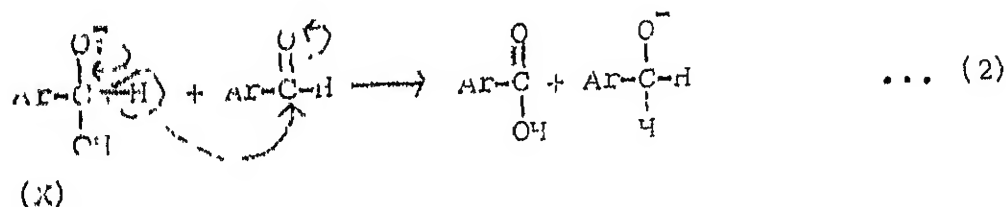
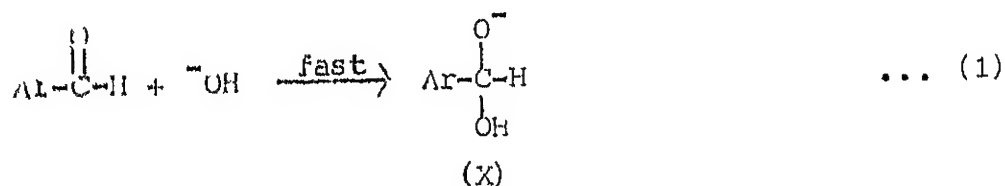
From the above discussion, it is evident that although mechanism of Cannizzaro reaction have been considered which may involve a hydride ion transfer or a hydrogen atom transfer, depending upon the conditions, a clear cut argument ruling out the

occurrence and hence transfer of a free hydride ion (incapable of free existence) has not been presented. We, therefore, decided to examine the rationale of the existing, acceptable mechanisms of Cannizzaro reaction in more detail.

V.3 Results and discussion

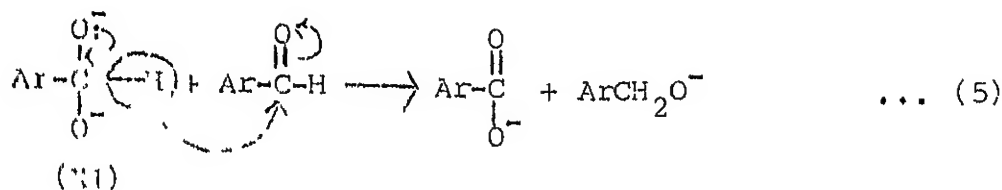
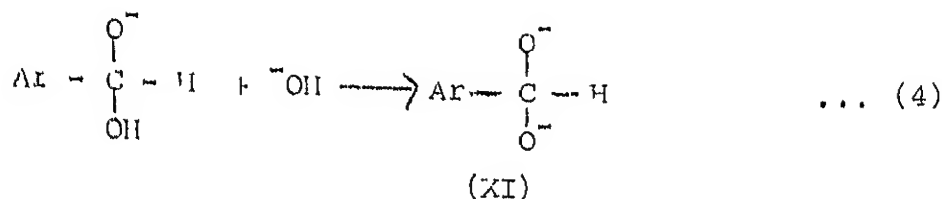
Although a variety of mechanisms for the Cannizzaro reaction have been discussed in the literature, the most widely accepted one currently invokes the hydride ion transfer as illustrated in Scheme V.1.

SCHEME V.1



OR (in strongly basic medium)

scheme V.1(contd.)

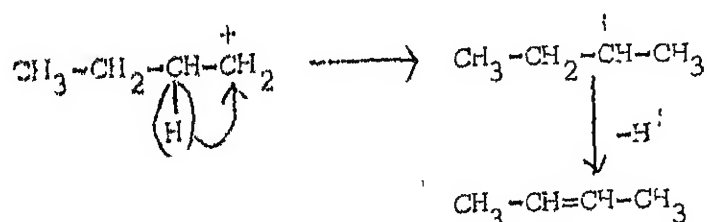


An argument in favor of this mechanism has been the fact that the benzylic alcohol produced does not take the α -hydrogen from the solvent for the reduction of the aldehyde; but that hydrogen comes from another molecule of the aldehyde itself.

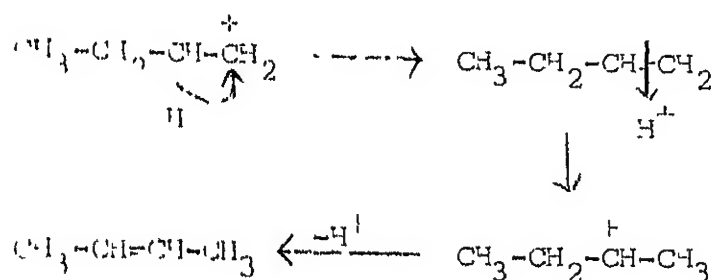
This mechanism further envisages that, if the hydride ion comes from the hydroxyalkoxide ion(X) then the final step is a rapid proton transfer. In the other case, however, the acid salt is formed directly and the alkoxide ion acquires a proton from the solvent giving the benzylic alcohol. However, the possibility of the reaction occurring via the dianion (XI) is rare and restricted only to the condition of highly basic media. Also, removal of a proton from the anion (X) even in highly basic medium to give the dianion (XI) would be energetically unfavourable. The occurrence of the Cannizzaro reaction successfully even when the hydroxide ion is replaced by an alkoxide ion (^-OR) in which case the formation of the dianion is not possible, also does not support the effective intervention of the dianion.

Even the mechanism covered by the steps 1,2 and 3 in Scheme V.1 suffers with serious defects. Thus, if in the hydroxy alkoxide ion (3), reversal of the charge from the negatively charged oxygen to carbon tending to form the carbonyl function takes place, the cleavage of one out of the three remaining bonds which will be energetically most favoured would be involving the C-O bond releasing hydroxide ion rather than the cleavage of the C-H bond releasing the hydride ion. Further, the electron affinity of the hydrogen being as low as that of sodium, the formation and transfer of the hydride ion should be inconceivable on energetic grounds. It is noteworthy in this connection that even the complex metal hydrides such as LiAlH_4 where a hydride bound to the metal actually exists, are now believed to reduce various substrates by donating of an electron and hydrogen atom rather than by hydride transfer.³⁹⁻⁴¹

We, therefore, suggest that where other conceivable pathways exist, involvement of hydride ion in any reaction should not be invoked. For example, in the following reaction (a part of E_1 dehydration of butan-1-ol) which is often exemplified in the literature as one involving a hydride shift need not be so described.



A better way to describe the same results would be to write the reaction as follows:



In order to rationalize the existing data on the Cannizzaro reaction in terms of an alternative, logical mechanism, we have carried out a study of this redox process. The results of our reactions of four aldehydes viz, benzaldehyde, p-chlorobenzaldehyde, p-bromobenzaldehyde and p-nitrobenzaldehyde with an excess of sodium hydroxide are listed in Table V.1.

Table V.1: Reaction of aldehydes (0.09 mol) with sodium hydroxide (0.0675 mol) in HMPA/THF (1:9), in dark, under N₂ atmosphere, at 25°C.

Run.	Aldehyde Ar-CHO	Reaction Time h.	% Yield of products	
			Alcohol (ArCH ₂ OH)	acid (ArCOOH)
1.	Benzaldehyde ^a (Ar=C ₆ H ₅)	36	32	30
2.	p-Chlorobenzaldehyde (Ar=p-Cl-C ₆ H ₄ -)	24	48	46

Table V.1(contd.)

Table V.1 (contd.)

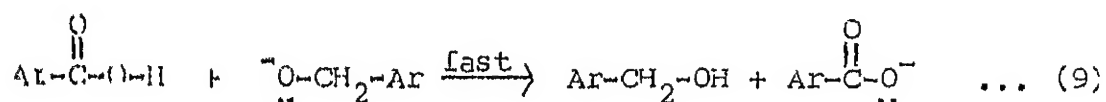
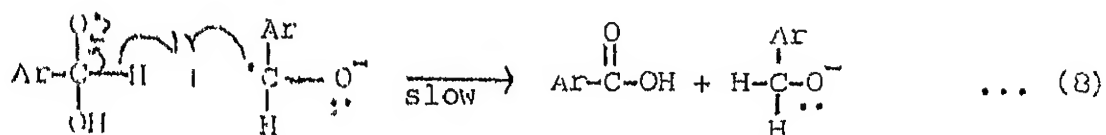
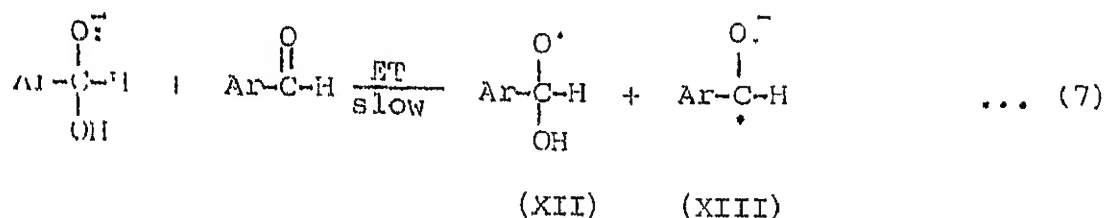
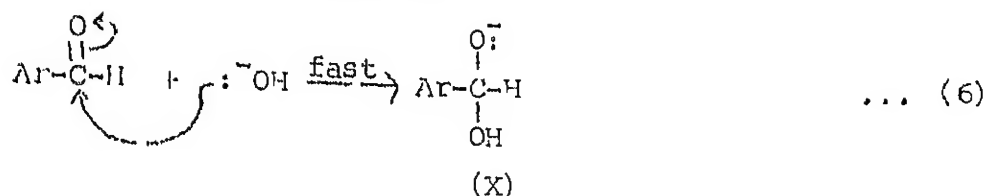
Run.	Aldehyde Ar-CHO	Reaction time h.	% Yield of products	
			alcohol (ArCH ₂ OH)	acid (ArCOOH)
3.	p-tolomobenzaldehyde (Ar=p-H-C ₆ H ₄ -)	24	46	45
4.	p-Nitrobenzaldehyde (Ar-p-NO ₂ -C ₆ H ₄ -)	24	41	45

a) Benzyl benzoate 17% and benzaldehyde 12% was also formed along with the alcohol and acid. This reaction being found slower than others (in run 2,3 and 4) was carried out for 36 h.

It is clear from these results that the reactions proceed cleanly to give the products inspite of very low solubility of sodium hydroxide in the medium and also that electronegative substituents in the aromatic nucleus facilitate the reactions.

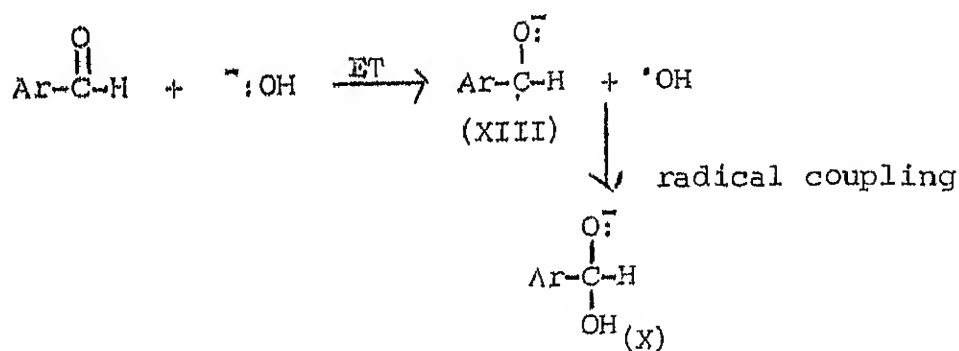
These observations, together with the facts recorded earlier in this chapter including the observation of resolvable ESR signals³⁰ in the reactions of the same aldehydes as well as the products obtained from C₆H₅CHO,²⁷ lead us to believe that the Cannizzaro reaction does not involve hydride ion. Instead an electron transfer radical mechanism presented in Scheme V.2 satisfactorily accounts for all the observations made by us and others.

SCHEME V.2



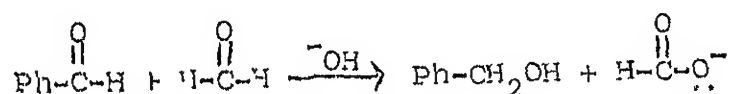
In the cases of aldehydes carrying electronegative groups in the aromatic nucleus where oxidizing power is enhanced, the electron transfer from the base (i.e., ^-OH in this case) may also take place giving (X) via (XIII) as shown in Scheme V.3.

SCHEME V.3



The bond homolysis shown in (Eqn. 8) would facilitate the cleavage of the C-H rather than the C-O bond in (XII). Also it appears that (XII) and (XIII), on their formation, remain in the close vicinity of each other to give the reaction represented by (Eqn. 8). Rarely, when (XIII) falls apart, it abstracts a hydrogen from the solvent instead of the one contained by the original aldehyde.

This mechanism accounts for the fact that hydrogenation catalysts like Raney nickel facilitate the process. The available data on the Cross-Cannizzaro reaction can also be rationalized well by means of this mechanism as shown for the reaction of benzaldehyde and formaldehyde in basic medium.



Here, the hydroxymethoxide anion would act as an electron donor in preference over the hydroxy alkoxide ion derived from benzaldehyde and benzaldehyde acts as a better electron acceptor compared to formaldehyde.

Further investigations are in progress.

V.4 Experimental

All melting points were recorded on a MEL-TEMP melting point apparatus. Infrared spectra were obtained on a Perkin-Elmer model 521 spectrophotometer. Literature melting points are taken from "Hand-Book of Chemistry and Physics", 50th edition, R.C. Weast (Ed.), published by the Chemical Rubber Company, Cleveland, Ohio.

Tetrahydrofuran (THF) was purified by keeping it over potassium hydroxide pellets overnight, refluxing over sodium for 5-6 h, and then distilling over sodium followed by distillation over lithium aluminium hydride. It was stored in contact with freshly drawn sodium wire and was used within two days of purification.

Hexamethyl phosphoric acid triamide (HMPA) was used after distilling over sodium.

All the aldehydes for use as available were commercially were purified before use by known methods.³¹ Authentic samples of p-chlorobenzoic acid,^{32a} p-bromobenzoic acid^{32b}, p-nitrobenzoic acid,^{32c} and p-chlorobenzyl alcohol,³³ p-bromobenzyl alcohol³⁴, p-nitrobenzyl alcohol³⁵ were prepared by known methods. Authentic samples of benzyl alcohol, benzoic acid and benzylbenzoate were used as commercially available.

Reaction of benzaldehyde (0.09 mol) with sodium hydroxide (0.0675 mol) in HMPA/THF (1:9) under N_2 atmosphere in dark for 36 h at room temperature ($30^\circ C$)

Benzaldehyde (0.09 mol; 9.5g) was placed in a three-necked RB flask mounted over a magnetic stirring base. HMPA/THF (10 ml/90 ml) was added to it through a dropping funnel. The system was flushed with N_2 gas for 30 min. Sodium hydroxide (0.27g, 0.0675 mol) was added to the contents of the flask and the mixture stirred at room temperature ($30^\circ C$) for 36 h in dark. The reaction occurred under heterogeneous condition as NaOH was not much soluble in the medium. After this period, the contents of the reaction flask were poured into water (200 ml) and the whole mixture extracted with 4x25 ml of ether. The ethereal layer was separated, washed first with water and then brine and dried overnight over anhydrous Na_2SO_4 overnight.

The ethereal extract, on evaporation of the solvent, gave a crude mixture of products which on analysis by GLC and NMR showed the presence of unreacted benzaldehyde (12%), benzyl alcohol (32%) and benzyl benzoate (17%) estimated by comparison of the peak areas with those of the authentic samples.

The aqueous layer was acidified with hydrochloric acid when a white precipitate separated out. This solid was extracted out in ether. The ethereal extract was washed with cold water and dried over Na_2SO_4 . After evaporation of the solvent a white solid

was obtained which after recrystallization from hot water was identified as benzoic acid (2.95g; 30%), m.p. found 120°C ; lit. m.p. 121°C .

Reaction of p-chlorobenzaldehyde (0.09 mol) with NaOH (0.0675 mol) in HMPA/THF (1:9) under N_2 atmosphere in dark for 24 h at room temperature 30°C .

In a 3-necked RB flask was placed p-chlorobenzaldehyde (12.0g; 0.09 mol) contained in HMPA/THF (10 ml/90 ml) mounted over a magnetic stirring base. Pure, dry N_2 was passed for 30 min to flush the system. NaOH (0.27g; 0.0675 mol) was then added to the flask and the contents stirred for 24 h in dark. After this time the heterogenous reaction mixture was poured into 200 ml of water and the resultant mixture extracted with 4x25 ml of ether. The ethereal layer was washed with water and dried overnight over anhydrous Na_2SO_4 . The dried ethereal extract was filtered and the solvent evaporated off by means of a cold air blower when a solid was obtained. This was identified by comparison with an authentic sample to be p-chlorobenzyl alcohol (5.65g, 48%). A sample recrystallized from ethanol was found to have m.p. 75°C , lit.m.p. 75°C .

The aqueous layer was acidified with hydrochloric acid when a white precipitate was formed which was washed several times with cold water. The product was found to be p-chlorobenzoic acid (5.5, 46%). A sample recrystallized from hot water was found to melt at 239°C , lit.m.p. 240°C .

Reaction of p-bromobenzaldehyde (0.09 mol) with NaOH (0.0675 mol) in HMPA/THF (1:9) under N_2 atmosphere in dark for 24 h at room temperature ($30^\circ C$).

Into a 3-necked RB flask mounted over a magnetic stirring base was placed 16.65g (0.09 mol) of p-bromobenzaldehyde and THF/HMPA (90 ml/10 ml). Pure dry N_2 gas was passed into this system for 30 min. After this, NaOH (0.27g, 0.0675 mol) was added and the mixture stirred at room temperature ($30^\circ C$) in dark for 24 h. Workup of the reaction was done by adding it to 200 ml of water. The resultant mixture was then extracted with 4x25 ml of ether. The ethereal layer was washed with water and dried overnight by keeping over anhydrous Na_2SO_4 . The dried ethereal extract was filtered and evaporated to dryness. Crystals of p-bromobenzyl alcohol (7.36g, 46%) so obtained were identified by the melting point, found $76^\circ C$, lit.m.p. $76^\circ C$; and comparison of the IR spectrum with that of an authentic sample.

To the aqueous layer was added HCl when p-bromobenzoic acid precipitated out. This was recrystallised from hot water, m.p. $251^\circ C$, lit.m.p. $252^\circ C$. The yield was found to be 7.07g, ~45%.

Reaction of p-nitrobenzaldehyde (0.09 mol) with NaOH (0.0675 mol) in HMPA/THF (1:9), under N_2 atmosphere, in dark for 24 h at room temperature ($30^\circ C$)

p-Nitrobenzaldehyde (13.59g; 0.09 mol) and HMPA/THF (10 ml/90 ml) were placed in a 3-necked RB flask mounted over a magnetic

stirring base and the system flushed with pure, dry nitrogen with stirring for 30 min. NaOH (0.27g, 0.0675 mol) was then added to the flask and the mixture stirred continuously for 24 h. After this time the reaction mixture was poured into 200 ml of water and the resulting mixture with ether. The ethereal layer was washed with water and dried over anhydrous Na_2SO_4 overnight. The dried ethereal extract was filtered off. On evaporation of the solvent a yellowish solid separated which was identified as p-nitrobenzyl alcohol, m.p. found 90°C , lit. m.p. 93°C . The yield was found to be 5.33g; 41%.

Hydrochloric acid was added to acidify the aqueous layer when a precipitate got separated out. This was washed several times with water and identified as p-nitrobenzoic acid, m.p. found 240°C , lit. m.p. 240°C . The yield was found to be 5.75g; 45%.

v.5 References

1. T.A. Geissman, Org. React., 1944, 2, 94.
2. Cannizzaro, Ann., 88, 129 (1853).
3. Claisen, Ber., 20, 646 (1887).
4. Kohn and Tranton, J. Chem. Soc., 75, 1155 (1899).
5. Vistschenko, Chem. Zentr., [II] 77, 1309, 1552 (1906).
6. A. Bachman, J. Am. Chem. Soc., 45, 2356 (1923).
7. A. Friedenhagen and K.F. Bonnoefier, Z. Phys. Chem., Abt. A, 181, 379 (1938).
8. E. Tommila, Ann. Acad. Sci. Fenn., A.59(8), 3-69 (1942); Chem. Abstr., 38, 6175 (1944).
9. M. Sonkus and W.G. Brown, J. Org. Chem. 3, 569 (1938).
10. E.R. Alexander, J. Am. Chem. Soc., 70, 2592 (1948).
11. G.P. Miklukhin and A.F. Rekasheva, J. Gen. Chem. USSR (Engl. Transl) 25, 1099 (1955).
12. C.G. Swain and D.R. Crist, J. Am. Chem. Soc., 94, 3199 (1972) and ref. no. 25 of the same.
13. K.J. Laidler, "Chemical kinetics", 1st ed., McGraw-Hill, New York, 1950, pp.96-101; 2nd ed., 1965, pp.137-143.
14. C.G. Swain, A.L. Powell, W.A. Sheppard and C.R. Morgas, J. Am. Chem. Soc., 101:13, 3578 (1979).
15. M.F. Hawthorne and E.S. Lewis, J. Am. Chem. Soc., 80, 4296 (1958).
16. C.G. Swain, D.A. Kuhn and R.L. Schowen, J. Am. Chem. Soc., 87, 1553 (1965).
17. C.G. Swain, A.L. Powell, T.L. Lynch, Sigma R. Alpha, R.P. Dunlap, J. Am. Chem. Soc., 101:13, (1979).

18. Pauling, "The Nature of Chemical Bond".
19. Sidgwick, "The Covalent link in Chemistry".
20. J. Weiss, Trans. Faraday Soc., 37, 783 (1941).
21. Doew, Ber., 20, 144 (1887).
22. Muller, Ann. Chem., 420, 241 (1920).
23. (a) Geisow, Ber., 37, 51⁴ (1904).
- (b) Hyford, J. Am. Chem. Soc., 29, 1227 (1907).
24. Kharasch, J. Am. Chem. Soc., 57, 1510 (1935).
25. Urushibara and Takebayashi, Bull. Chem. Soc., Japan, 12, 328 (1937).
26. Dolepine and Horeau, Bull. Soc. Chim. France, 4, 1524 (1937).
27. Sung-Keo Chung, J. Chem. Soc., Chem. Commun. 480 (1982).
28. C.R. Hanser, P.J. Hamrick, Jr., and A.T. Stewart, J. Org. Chem., 21, 260 (1956).
29. S.K. Chung and F.F. Chung, Tetrahedron Lett., 2473 (1979).
- S.K. Chung, J. Org. Chem., 45, 3513 (1980).
30. E.C. Ashby, David T. Coleman III and M. Pilar Gamasa, Tetrahedron Lett., 24(a), 851 (1983).
31. A text-book of Practical Organic Chemistry, A.I. Vogel, 692.
32. (a) *ibid*, pp.760.
- (b) Beilstein 9², 233.
- (c) A.I. Vogel, *ibid*, pp.757.
33. A. McKillop and M.E. Ford, Tetrahedron, 30, 2467 (1974).
34. Org. Reactions VI, 491 (1951).
35. Beilstein VI², 424.

36. U.R. Nayak and Sukh Dev, *Tetrahedron*, 19, 2293 (1963).
37. G.W.K. Cavill and D.L. Ford, *Aust. J. Chem.*, 13, 296 (1960).
38. Haber and Willstätter, *Ber.*, 64, 2844 (1931).
39. P.R. Singh, J.M. Khurana and Alok Nigam, *Tetrahedron Lett.*, 2901 (1981).
40. P.R. Singh, R.K. Khanna, *Tetrahedron Lett.*, 1411 (1983).
41. P.R. Singh, Alok Nigam and J.M. Khurana, *Tetrahedron Lett.*, 4753 (1980).
42. Kling and Roy, *Compt. Rend.*, 144, 1113 (1907).

CHAPTER VI

SUMMARY AND CONCLUSION

In this thesis, reactions of five different categories have been examined in some detail and new mechanistic interpretations offered in each case. Various categories of reactions are:

- (i) reactions of diorganomercury compounds with sodium naphthalene in THF medium at room temperature under nitrogen atmosphere
- (ii) reactions of diorganomercury compounds with lithium aluminium hydride in THF solvent at room temperature under nitrogen atmosphere
- (iii) reactions of α -hydroxy acids and their salts with N-bromosuccinimide in dry DMF at reflux temperature
- (iv) reactions of primary benzylic halides with sodium naphthalene in THF solvent at temperatures ranging from 0° to -10°C

- (v) reactions of benzaldehyde and its p-substituted derivatives with an excess of NaOH in THF/HMPA (9:1 by volume) medium at room temperature

The reactions of dibenzyl mercury, diphenyl mercury and phenyl p-tolyl mercury with varying amounts of sodium naphthalene in THF solvent were examined at 30°C under nitrogen atmosphere. Instantaneous separation of metallic mercury was observed in each reaction. In addition, naphthalene, monomeric hydrocarbons and dimeric hydrocarbons in the reactions of symmetrical diorganomercury compounds; and mixtures of biaryls in the reactions of unsymmetrical diorganomercury compounds were obtained. The recovered starting materials from incomplete reactions of unsymmetrical diorganomercury compounds contained small amounts of symmetrical diorganomercury compounds also. On the basis of our observations, an electron transfer free radical mechanism involving the initial occurrence of a $n^{\bullet} \longrightarrow n^{\bullet}$ electron transfer from the naphthalene radical anion to the diorganomercurials has been proposed.

The reactions of the same diorganomercury compounds with LiAlH_4 in THF solvent at 30°C under dry nitrogen atmosphere commenced with evolution of hydrogen and simultaneous separation of metallic mercury. Here too, an electron transfer mechanism with LiAlH_4 as the donor and the diorganomercurial as the acceptor has been proposed which satisfactorily accounts for the initial generation of radicals and anionic intermediates, besides rationalising all the observations recorded for these reactions.

Oxidative decarboxylation of the salts of α -hydroxy acids viz. glycolic, mandelic and benzilic acids as well as glycolic and benzilic acids themselves using N-bromosuccinimide has been studied at reflux temperature in dimethylformamide medium with a view to understanding the mechanistic details. Reactions using the two reactants in equimolar ratios were largely incomplete; but doubling the quantity of the oxidant, N-bromosuccinimide resulted in the completion of the reaction under otherwise similar conditions. In view of the observations made, an electron transfer mechanism in which the acid or its salt reduces the N-bromosuccinimide in the first step has been proposed. It has been found that succinimidyl anion, bromine atom and the radical derivable by the initial loss of an electron from the anion of the α -hydroxy acid serve as the precursors of different products viz. carbon dioxide, molecular bromine and succinimide.

Reactions of sodium naphthalene with equimolar quantities of benzyl chloride, p-nitrobenzyl bromide, 1-chloromethylnaphthalene, 9-chloromethylantracene in THF at temperatures ranging from 0° to -10°C under nitrogen atmosphere have also been examined. While initial generation of free radical intermediates as a consequence of electron donation by the naphthalene radical anion to the primary benzylic halides occurs in all the reactions, carbanions are also produced by subsequent reduction of the radicals. The radicals and carbanions both intervene in the formation of the products.

Reactions of benzaldehyde and its para substituted derivatives with an excess of sodium hydroxide have been found to lead to the products in accordance with the Cannizzaro reaction. Arguments have been presented which make the commonly accepted, hydride transfer mechanism of the Cannizzaro reaction appear irrational. However, according to our initial thinking an electron transfer mechanism involving hydrogen atom transfer proposed for these reactions appears to account for all the observations concerning these reactions. Further work on the verification of the new mechanism is being continued.

Studies reported in this thesis have thus led to mechanisms involving electron transfer for some redox reactions of diorgano-mercury compounds, α -hydroxy acids and their salts, primary benzylic halides and aromatic aldehydes. Besides their mechanistic significance, these electron transfer reactions may conceivably provide convenient, mild condition routes to otherwise cumbersome chemical transformations.

7h

547.139

C 394n

A99207

CHM-140 (5-1) - CHJ - A/E W 12 11 11 11 11

7h
547-139
C394n

Date Slip **A** 99207

This book is to be returned on the
date last stamped.

[illegible]